Stock Assessment of Pacific Cod (*Gadus macrocephalus*) in Georgia and Juan de Fuca Straits, 1954-84

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January 1987

Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 1905

87-04656/

Canadian Manuscript Report of Fisheries and Aquatic Sciences

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by

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Cat. No. Fs 97-4/1905E ISSN 0706-6473

Correct citation for this publication:

Westrheim, S. J. and R. P. Foucher. 1987. Stock assessment of Pacific cod (Gadus macrocephalus) in Georgia and Juan de Fuca straits. Can. MS Rep. Fish. Aquat. Sci. 1905: 84 p.

ABSTRACT

Westrheim, S. J. and R. P. Foucher. 1987. Stock assessment of Pacific cod (Gadus macrocephalus) in Georgia and Juan de Fuca straits. Can. MS Rep. Fish. Aquat. Sci. 1905: 84 p.

Four important stocks of Pacific cod were delineated in Georgia and Juan de Fuca straits, primarily based on results of extensive Canadian and U.S. tagging experiments during 1954-79. All four stocks were exploited seasonally, almost exclusively by on-bottom trawls. Two stocks were resident year-round (MSA 14 and Gulf Islands), and two were itinerant and seasonal (Nanoose and MSA 19).

Standardized landing statistics and landings-at-age were employed to assess each stock. No stock exhibited symptoms of recruitment overfishing, despite relatively high estimates of total mortality rate ($Z = 1.03 - 1.50$). Estimates of M (0.59) and q (1.373×10^{-3}) were obtained from only one stock (MSA 14), by regressing Z on effort.

Yield-per-recruit analysis indicated that maximizing YPR was impractical because the required mesh size was too large for the mixed-species fishery. Current legal, minimum mesh (4.25", synthetic materials) was satisfactory for maximizing catch profitability (YPR/F).

RESUME

Westrheim, S. J. and R. P. Foucher. 1987. Stock assessment of Pacific cod (Gadus macrocephalus) in Georgia and Juan de Fuca straits. Can. MS Rep. Fish. Aquat. Sci. 1905: 84 p.

D'après les résultats d'importantes expériences d'étiquetage menées de 1954 à 1979 par des chercheurs canadiens et américains, les auteurs ont identifié quatre grands stocks de morue du Pacifique dans les détroits de Géorgie et Juan de Fuca. Ces quatre stocks ont fait l'objet d'une exploitation saisonnière presque exclusivement par chalutage sur le fond. Deux de ces stocks vivent en permanence dans la région (ZSS 14 et îles Gulf) tandis que les deux autres se déplacent et fréquentent les région sur une base saisonnière (Nanoose et ZSS 19).

Les auteurs ont utilisé les statistiques normalisées sur les débarquements et les prises débarquées selon l'âge pour évaluer chaque stock. Aucun des stocks ne montrait de signes de sur exploitation aux dépens du recrutement malgré des estimations relativement élevées du taux de mortalité totale (Z=1,03-1,50). Des estimations de M (0,59) et de q (1,373 x 10^{-3}) ont été obtenues pour un seul stock (ZSS 14) par régression de Z en fonction de l'effort.

Une analyse du rendement par recrue a indiqué que la maximalisation du RPR n'était pas pratique parce que le maillage requis était trop grand pour la pêche polyspécifique. Le maillage légal actuel (4,25'', matière synthétique) est satisfaisant pour la maximalisation de la rentabilité des prises (RPR/F).

INTRODUCTION

Pacific cod (Gadus macrocephalus) is an important component in the British Columbia trawl fishery. Principal sources of supply are the grounds off the southwest coast of Vancouver Island (Area 3C), and in Queen Charlotte Sound (Areas 5A + 5B) and Hecate Strait (Areas 5C + 5D) (Fig. 1). A secondary source is the southern portion of Area 4B -- Georgia Strait and Juan de Fuca Strait.

Although the fishery for Pacific cod in Area 4B is the oldest, without interruption, no detailed assessment of the Pacific cod stock(s) has been undertaken. Principal reasons appear to be the lack of data on age-composition of landings, and/or standardized trawling effort. Both deficiencies may have been overcome by the reports of Foucher and Giudici (1985), and Westrheim and Foucher (1985a).

The purpose of this report is twofold: stock assessment and yield optimization.

MATERIALS AND METHODS

STOCK DELINEATION

Four important stocks of Pacific cod have been delineated in Area 4B -- Minor Statistical Area (MSA) 14, Nanoose (MSA 17-N), Gulf Islands (MSAs 17-S and 18), and MSA 19 (Fig. 2). Evidence for delineation of all but MSA 19, is based primarily on the results of Canadian tagging experiments during 1954-62 (Westrheim 1982) and 1978-79 (Westrheim 1985); and U.S. tagging experiments in 1955-70 (Gosho 1976) and 1977 (Bargmann 1980). Delineation of the stock in MSA 19 is based on landing records, diet, gonad condition, and herring behaviour (Westrheim and Pedersen, 1986).

The stocks in MSA 14 and the Gulf Islands are primarily resident year-round, but are fished seasonally due to regulations and/or economics (Westrheim 1980).

The itinerant Nanoose stock appears on the small trawling grounds outside Nanoose Bay only during the spawning season, January-March (Forrester and Ketchen 1963). For the remainder of the year, its principal locations appear to be southeast Georgia Strait (MSAs 29, 80, 82, 83), Gulf Islands (MSAs 17-S and 18), and MSA 14, based on the results of Canadian and U.S. tagging experiments referred to earlier.

The itinerant MSA 19 stock is a recent phenomenon, 1974-84, and appears to be a transitory concentration of cod temporarily lured inshore by the anomalous behaviour of herring on their inshore spawning migration (Westrheim and Pedersen, 1986).

Stock delineation was proposed in two previous studies -- Forrester and Ketchen (1963) and Ketchen et al. (1983). The former proposed two stocks (MSA 14 and MSAs 17 + 18), based on results of the Canadian tagging experiments during the 1954-59 (the MSA 19 fishery was minor at that time). The latter authors suggested "several intermingling units", not quantifiable (op cit. p. 1105), based on tagging analyses of (Gosho 1976) and Westrheim (1982). The four stocks proposed in the current study are also unquantifiable, with available data.

MATERIALS AND METHODS

LANDING STATISTICS

Time, space, and utilization restraints employed by Westrheim and Foucher (1985b) for calculating relative fishing power, were also employed in the present study for calculating LPUE (landings per hour trawled). With respect to time, the year was defined as October - September, due to the seasonal nature of the fisheries in Area 4B. During 1945-84, Quarters I and IV provided 77.8% of the annual landings (Westrheim and Foucher 1985a, Table 2). With respect to space, the important MSAs within Area 4B were identified as 14 (11.9%), 17 (16.0%), 18 (33.3%), 19 (24.6%), and, possibly 20 (8.7%) (op. cit. Table 3). All other MSAs combined (12, 13, 15, 16, 28, 29) accounted for only 5.5%. All important MSAs, except 20, exhibited the traditional seasonal pattern of landings. With respect to utilization, all subsequent computations were based on landings for human consumption -- 98.6% of the 1955-84 landings of Pacific cod (op. cit. Table 4).

Landings. Records of total landings of Pacific cod during 1945-84 were taken from Foucher and Giudici (1985). Records for 1985 were taken from computer files at the Pacific Biological Station (Nanaimo, B.C.), and are provisional at this time (June 1986). Total landings are computed from sales-slips which are completed by the processor at the time of purchase. These records include weight purchased by species; location (major and minor statistical area) where "most" of the catch was taken; and numbers of days fished. A variable proportion of the sales-slip landings are also categorized as interviewed landings.

Interviewed landings are computed from records completed by our port liaison officers, stationed in Vancouver and Prince Rupert, from interviews with the vessel captains at the time of landing. These detailed records include locations (major and minor statistical area, and ground), depth

trawled, and hours trawled at each location during the trip, and are stored in computer files at the Pacific Biological Station. Time series is 1954-85. For this study, landing statistics were compiled by important MSA, rather than ground, because of the relatively small proportions of interviewed landings among MSAs.

Interviewed landings comprised 57.0% of total landings during 1955-84, MSAs combined, but ranged among 5-year periods, from 4.1% (MSA 18, 1980-84) to 99.3% (MSA 14, 1960-64) (op. cit. Table 5). Among important MSAs, interviewed landings comprised 79.2-99.3% for MSA 14, 8.6-90.1% for MSA 17, 4.1-60.8% for MSA 18, and 23.4-47.8% for MSA 19. The low values for MSAs 17 and 18 occurred during 1980-84.

One possible source of error in our computations, based on interviewed landings, would be a differential choice of port of landing based on vessel size, or "efficiency" (horsepower class). If smaller vessels preferred the ports on Vancouver Island, our interviewed data would be based on the larger vessels landing in Vancouver or vicinity, where the port-liaison officers are stationed. Fortunately, such is not the case. For each of the important MSAs, the mode and distribution of vessels, by horsepower class, were the same for the total fleet as those interviewed, in each five-year period, 1955-59 through 1980-84 (Table 1).

Effort. Nominal interviewed effort, collected by port-liaison officers, was standardized to vessels in gear-class 3 (double-gear & drum) and horsepower-class 3 (200-299 hp), by the method of Westrheim and Foucher (1985a). Total standardized effort is calculated by dividing total landings by standardized LPUE (kg/h).

LPUE. Standardized LPUE (kg/h) was calculated by dividing interviewed landings by standardized interviewed effort, at the 40% qualification level. That is, only landings in which Pacific cod comprised at least 40% of the all-species total. For this study, LPUEs were calculated for October-March, except Nanoose (MSA 17-N), where the fishery is restricted, by regulation, to January-March.

Selection of the 40% qualification level follows that of Westrheim and Foucher[a] (1985a), who tested four levels -- 0%, 20%, 40%, and 60%. The former two levels were rejected to avoid inclusion of landings in which "other "targeted" species were included, such as spiny dogfish (Squalus acanthias) and walleye pollock (Theragra chalcogramma)" (op. cit. p. 6). The 60% qualification level was rejected because LPUEs were close to those for 40%, but less landings were involved.

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[a]They regressed mean RFPs ($=LPUE_1/LPUE_3$) of gear-class 3 vessels on horsepower class (100-unit intervals) to obtain estimates of relative fishing power.

AGE COMPOSITION OF LANDINGS

Records of Pacific cod age compositions (nos. landed) in landings from Area 4B, by important MSA and quarter-year, were taken from Foucher and Giudici (1985, Tables 9-14). They employed the Foucher-Fournier (1982) method to derive age-frequencies from length-frequencies. The records span the period 1950-84, but are intermittent among years in all area-time cells.

Age compositions in numbers landed per hour trawled were computed by dividing numbers landed by standardized effort.

The seasonal nature of the fisheries prevented the collection of adequate numbers of length-frequency samples throughout each year. Based on the samples in hand, January-March was selected as the representative quarter-year, with respect to age composition of October-September landings, for the MSA 14, Nanoose, and Gulf Island cod stocks. October-December was selected for the MSA 19 stock.

MORTALITY RATES AND CATCHABILITY COEFFICIENTS

Total. Instantaneous total mortality rate (Z) was computed in the conventional manner of regressing ln nos./h at age on age. The slope of the regression line is an estimate of Z. This method was applied to three sets of data for selected age-classes (3-6 or 2-5) -- (1) mean age-frequencies among years; (2) mean Z among selected year-classes; and (3) mean age-frequencies among selected year-classes.

Natural. Instantaneous natural mortality rate (M) was computed by regressing Z on standardized effort among year-classes, whereby the intercept is an estimate of M. This method is analogous to $Z=M+qf$ (Beverton and Holt 1957), where f = fishing intensity = effort/area, if the trawling area is reasonably constant during the study period.

Catchability coefficient. The catchability coefficient (q) was computed by regressing Z on standardized effort among year-classes, whereby the slope is an estimate of q.

Fishing. Instantaneous fishing mortality rate (F) was computed by two methods -- subtraction ($F = Z - M$) and multiplication ($F = q\bar{E}$), where E = mean annual standardized effort.

YIELD PER RECRUIT (YPR)

A yield-per-recruit analysis was employed to determine optimal harvesting strategies with respect to yield and catch profitability. Yield is here defined as weight landed for sale.

Catch profitability (YPR/F) was defined as the quotient of yield-per-recruit and fishing mortality rate. This index was created to further refine the concept of yield, so as to include a "catching cost". That is, F is positively related to effort, which is positively related to the cost of fishing.

Variables included in the YPR computations were: natural mortality rate (M), fishing mortality rate (F), trawl mesh size (in lieu of age at recruitment), and minimum commercial size (MCS), imposed by the processing plants.

Natural (M) and fishing (F) mortality rates were assumed to be constant throughout the cohort's life, after age 1.0. Selected natural mortality rates were 0.4 and 0.6. Selected fishing mortality rates ranged from 0.2 to 1.2, in increments of 0.1.

Selected trawl mesh sizes (internal measure) ranged from 3.0 to 9.0 in (76-229 mm), in 0.5-in (13-mm) increments. Selectivity of each mesh size over the appropriate size range of the cod was established in three steps: (1) length at 50% retention, computed by the method of Margetts (1957); (2) lengths at 25% and 75% selection, determined empirically by Hodder and May (1965); and (3) estimating, by extrapolation by eye, the retention percentage at lengths less than the 25% retention length, and at lengths greater than the 75% retention length (Table 2).

Margetts (op. cit.) determined that the 50% retention girth was 80% of the internal perimeter of the mesh. For Pacific cod, the length-girth relationship was determined to be $L = 1.5772\ G + 5.1647$, based on Westrheim's (1977) empirical formula of $G = 0.63405\ L - 3.2747$ ($R^2 = 0.99+$), over the size range of 17-71 cm.

Hodder and May (1965) determined empirically that the length interval spanning the 25-75% retention level was 10 cm, and was symmetrical about the length at 50% retention. Table 3 contains the computed values of 50% retention lengths for the selected mesh sizes in this study, and corresponding mean age.

Minimum commercial size (MCS), imposed by the fillet plants, varied from 16 in (41 cm) to 18 in (46 cm), based on an examination of length-frequency samples from cod landings. In this study we have used two minima -- 41 and 46 cm. For fish retained by the net but smaller than the minimum market size, we have assumed a 100% mortality rate, and their weight was not included in the yield. For fish escaping through the meshes, we have assumed no mortality due to the net.

Mean lengths at age, and associated standard deviations, of cod age-classes 3-8 were derived, as a by-product, from the Foucher-Fournier (1982) method of converting length-frequencies to age-frequencies. Since commercial landings contain biased samples of age-1 and age-2 cod, estimates of mean lengths for these age-classes were obtained empirically from research-vessel catches.

For age-classes 2-8, mean lengths were computed for each selected MSA, based on monthly mean lengths during January-March 1954-82 (Table 4). Mean lengths within age-classes were similar, except for the smaller mean lengths for age-2 cod from MSA 19. They reflect the smaller minimum commercial size which was in effect during 1978-83 for cod landed from MSA 19. The pooled mean lengths, among MSAs, were chosen to represent age-classes 3.0-8.0, viz., 58.3, 65.8, 71.7, 76.4, 80.2, and 82.9 cm, respectively. No statistical tests were employed to detect differences in mean lengths of each age-class among MSAs, because the Foucher-Fournier (1982) method begins with estimates of mean length and standard deviation for each age-class.

Estimates for ages 1.0 and 2.0 were 26 and 47 cm, respectively. The birthdate was arbitrarily selected to be March 1, mid-point in the spawning season (primarily February-March). The estimate for age 1.0 was rounded from 26.1, the estimate of Ketchen (1961a, Table VIII). The estimate for age 2.0 was calculated as the mean from four sources: the mean length, adjusted for difference in dates, from the age-2 mode of fish tagged in 1978 in Swanson Channel (Leaman et al. 1979) - 45.8 cm; the equivalent mean length for 1979 (Foucher et al. 1979) - 44.9 cm; the mean length of Ketchen (1961a), adjusted for difference in dates - 49.2 cm; and the pooled mean for Area 4B for all samples from 1954-83 (Table 4) - 47.6 cm.

Von Bertalanffy growth parameters (K, L_∞, and t_o) were estimated from the selected mean lengths at age using the non-linear regression computer program (April 1985 version) of BMDP Statistical Software Inc., developed at the Health Sciences Computer Facility of the University of California at Los Angeles (Dixon and Brown 1979). The parameters were used to compute the expected mean lengths at each stage of the cohort's life.

The formula for converting length to weight was that of Westrheim (1977) for months other than the spawning season:

$$W = 0.007377\ L^{3.0963}$$

where W = weight in grams,
and L = fork length in centimeters.

RESULTS

LANDING STATISTICS

Introduction

Pacific cod is the single most important species landed from Area 4B by the on-bottom trawl fleet. During 1945-84, this species comprised 45.0% of the all-species landings. Among 5-year periods during 1955-84, comprising

most of our study period, Pacific cod comprised 42.3-58.3% of the all-species landings (Westrheim and Foucher 1985a, Table 1).

During 1945-85, annual landings of Pacific cod exhibited differing trends among important MSAs, except that a general decline was evident after 1981 (Fig. 3). This latter decline occurred in all offshore stocks as well, and has been attributed to a coastwide decline in cod abundance, caused by adverse environmental factors (Westrheim and Foucher 1985b). Landings from MSA 14 peaked in 1954, at nearly 400 t, and subsequently have been oscillating around 100-200 t. Landings from MSA 17 oscillated around 150 t/y, without trend, until 1971, but exhibited an uninterrupted decline thereafter. The Nanoose portion of these was 57% during 1954-84 (Foucher and Giudici 1985, Tables 4 and 8). Landings from MSA 18 have oscillated around 200 t/y without trend. Landings from MSAs 19 and 20 were negligible prior to 1974, but became temporarily substantial during 1974-84 and 1979-84, respectively.

MSA 14 (Fig. 4, Table 5)

Trawling effort, during October-September 1954-85, ranged from 112 h (1978-79) to 947 h (1954-55), with a moderate downward trend. Mean annual effort was 397 h, and was less than 400 h in 24 of the 29 y of usable data. No estimate was made for 1973-74 due to the lack of interviewed landings for October-December.

Landings ranged from 17 t (1968-69) to 252 t (1954-55). Mean annual landing was 83 t, and annual landings were less than 100 t in 21 of the 31 y. Landings were relatively small during 1964-70 (17-35 t).

LPUEs ranged from 76 kg/h (1967-68) to 429 kg/h (1978-79) with a moderate upward trend. Mean annual LPUE was 219 kg/h, and annual values were less than 300 kg/h in 22 of the 29 y of usable data. Relatively high LPUEs (303-445 kg/h) occurred during 1974-81.

In summary, Pacific cod abundance in MSA 14 has exhibited moderate fluctuations during 1954-84, and was maximal during 1974-81. Abundance has been declining since 1980-81, but has not yet reached the low level of 1965-69.

Nanoose (Fig. 5, Table 6)

Pacific cod landings from Nanoose (MSA 17-N) comprised 89% of the cod landed from MSA 17 during January-March 1954-84 (Foucher and Giudici 1985, Table 8). January-March cod landings from MSA 17 comprised 77% of the January-December landings during 1945-84 (op. cit. Table 1).

Trawling effort expended at Nanoose during January-March 1954-75 ranged from 111 h (1975) to 668 h (1960), with a slight downward trend. Mean annual effort was 317 h, and was less than 500 h in 18 of the 21 y. No estimates of effort were possible for 1966, 1976-78, and 1980-84, because of small landings and/or small proportions of interviewed landings.

Landings of Pacific cod from Nanoose during 1954-75 ranged from <0.5 t (1966) to 303 t (1971), with a slight upward trend. Mean annual landing was 110 t, and in 16 of the 21 y, landings were less than 150 t. After 1974, annual landings never exceeded 36 t.

LPUEs of Pacific cod from Nanoose during 1954-75 ranged from 114 kg/h (1969) to 656 kg/h (1959), with a slight upward trend. Mean annual LPUE was 337 kg/h, and in 15 of the 21 y, LPUE was less than 400 kg/h. Estimates of LPUE were not possible for 1966, 1976-78, and 1980-84, due to the paucity, or absence, of interviewed landings.

In summary, apparent relative abundance of Pacific cod at Nanoose exhibited substantial fluctuations without appreciable trend, during 1954-75. Subsequently, abundance has remained at a low level. We do not believe the fishery is responsible for the decline in abundance, and its sustained low level. Evidence to support our opinion is provided in a subsequent section (STOCK ASSESSMENT).

Gulf Islands (Fig. 6, Table 7)

Trawling effort during October-September 1954-79 ranged from 894 h (1978-79) to 3,215 h (1954-55), with a moderate downward trend. Mean annual effort was 1690 h, and in 17 of the 25 usable years, effort was less than 2000 h. No estimates were possible for 1979-85 due to the paucity, or absence, of interviewed landings and effort.

Landings during October-September 1954-84 ranged from 93 t (1983-84) to 627 t (1954-55), and exhibited a slight downward trend. Mean annual landing was 270 t, and in 20 of the 30 usable years, landings were less than 300 t. Landings were relatively high (262-499 t) during 1973-81, but declined sharply thereafter to no more than 20 t in 1984-85. The landings in 1984-85 are based only on MSA 18 records, as no interviewed landings were available from MSA 17 to partition into 17-N and 17-S.

LPUEs during October-September 1954-79 ranged from 96 kg/h (1961-62) to 330 kg/h (1978-79), and exhibited a moderate upward trend. Mean LPUE was 170 kg/h, and in 18 of the 25 usable years, was less than 200 kg/h. LPUE was relatively high (203-499 kg/h) during 1971-79. LPUEs for 1979-85 are unusable, or unknown, due to the paucity, or absence, of interviewed landings and effort.

In summary, Pacific cod abundance in the Gulf Islands has fluctuated moderately, without appreciable trend; was relatively high during 1971-79; and has subsequently declined sharply.

MSA 19 (Fig. 7, Table 8)

The fishery for Pacific cod in MSA 19 was intermittent and inconsequential until 1974-75, when it suddenly "blossomed". Details on the "new" fishery and its cause were reported in Westrheim and Pedersen (1986).

Probable cause was the anomalous behaviour of Pacific herring (Clupea harengus pallasi) (Westrheim and Pedersen 1986). Briefly, this behaviour consisted of a portion of the herring stock "summering" some 35 nautical miles south of their customary offshore ground, and subsequently occupying a pre-spawning staging area (MSA 19) some 35 nautical miles short of their customary pre-spawning staging area in the Gulf Islands.

Effort, during 1974-84, ranged from 570 h (1976-77) to 3865 h (1979-80), and has been generally declining since 1979-80. In 5 of the 10 years, effort was greater than 1000 h, but less than 2000 h. Effort has generally fluctuated directly with landings.

Landings ranged from 244 t (1976-77) to 928 t (1981-82), and have declined sharply since 1981-82. In 6 of the 10 years, landings were greater than 200 t, but less than 600 t.

LPUEs ranged from 227 kg/h (1974-75) to 428 kg/h (1976-77), without evident trend. In 9 of the 10 years, LPUEs were greater than 200 kg/h, but less than 400 kg/h.

In summary, Pacific cod LPUEs do not reflect abundance of Pacific cod in MSA 19, primarily because of the close relationship between effort and landings. Evidently, the trawl fleet reacts opportunistically to the abundance of cod in MSA 19. Three factors contribute to this phenomenon: (1) close proximity of the trawling grounds to major ports; (2) small area of grounds; and (3) land-mass protection of the grounds from adverse weather. Total landings are probably the best available index of cod abundance in MSA 19. This index suggests that abundance rose steadily from 1974-75 through 1981-82, then declined sharply.

MSA 20 (Fig. 8, Table 9)

The Pacific cod fishery in MSA 20 has been relatively unimportant, with respect to those in other important MSAs (Fig. 2). Pacific cod ranked second to Dover sole (Microstomus pacificus) within MSA 20 -- 18% vs 53% during 1945-46 through 1959-60, and 33% vs 36% during 1960-61 through 1976-77 (Westrheim 1980, Table 20). Furthermore, Pacific cod landings from MSA 20 were not seasonal, as noted for the other important MSAs.

During most of 1954-85, Pacific cod landings, during October-September were relatively small (13-116 t). Only during 1978-79 through 1980-81 was there a brief rise in "importance" (203-243 t), which probably reflected the new, and probably transitory, fishery in adjacent MSA 19.

Detailed analysis of Pacific cod landing statistics for MSA 20 was precluded by the paucity, and intermittent nature, of the data. In general, landings appear to be fluctuating without trend.

Summary

Exploitation histories differ among the four stocks, but in no case is there evidence from landing statistics that the fisheries adversely affected stock abundance. Abundance of the resident stocks in MSA 14 and Gulf Islands fluctuated without trend throughout the study period, 1954-84. The decline in landings from Nanoose, after 1971 will be discussed in the STOCK ASSESSMENT Section. The 12-year rise and fall of cod landings for MSA 19, and to a much lesser extent from MSA 20, was attributed to the anomalous behaviour of adult herring inshore-bound to spawn in Area 4B (Westrheim and Pedersen 1986).

MORTALITY RATES

MSA 14

Twenty-three years of usable age-frequency data were avialable for Pacific cod landed from MSA 14 during January-March 1954-84 (Table 10). No samples were collected in 1974 and 1981, and length-frequency samples were deemed too small in 1965 (N=84), 1969 (N=63), 1977 (N=120), and 1980 (N=120) (Foucher and Giudici 1985, Appendix table 1). Age-frequency data for the other three quarter-years are contained in Appendix table 3.

Age-frequency data for 6 year-classes were deemed usable for computing mortality rates -- 1952-54, and 1956-58 (Table 11). The remainder were deemed unsatisfactory due to missing or unrealistic data.

Estimates of Z. Three estimates of Z were obtained, based on age-classes 3-6 (Table 12). From the mean age-frequencies among years, Z=1.03, by regression (R^2=0.97). Among selected year-classes, Z=1.34 (C.V.=27%); and from the mean age-frequencies among selected year classes, Z=1.24, by regression (R^2=0.99).

Estimates of M and q. Regressing Z on mean annual effort among year-classes, yielded M=0.59, and $q=1.373 \times 10^{-3}$ (R^2=0.32) (Table 11).

Estimates of F. Five estimates of F were obtained -- three by subtraction ($F = Z-M$), and two by multiplication ($F = q\bar{E}$) (Table 12). The estimates by subtraction were 0.45 (mean age-frequencies among years), 0.65 (mean age-frequencies among selected year classes), and 0.75 ($\bar{Z}$ among selected year-classes). The two estimates by multiplication were 0.55 ($q\bar{E}$ among years) and 0.50-1.02 ($q\bar{E}$ among selected year-classes). The relatively high values (0.86-1.02) for the 1952-54 year-classes reflect the corresponding high effort values for 1954-55 through 1959-60 (Fig. 4; Table 5). In contrast, the values (0.50-0.62) for the 1956-58 year-classes reflect the "average" effort expended during 1960-61 through 1983-84.

Nanoose (MSA 17-N)

Twenty-three years of usable age-frequency data were available for Pacific cod landed from Nanoose during January-March 1954-84 (Table 13). No samples were collected in 1966, 1976, and 1977 (Foucher and Giudici 1985, Appendix table 1).

Age-frequency data for 13 year-classes were deemed usable for computing mortality rates -- 1951-59, 1964-65, and 1968-69 (Table 14). The remainder were deemed unrealistic due to missing or unrealistic data.

Estimates of Z. Three estimates of Z were obtained, based on age-classes 3-6 (Table 12). From the mean age-frequencies among years, Z=1.35, by regression (R^2=0.99+). Among selected year-classes, $\bar{Z}$=1.50 (C.V.=21%); and from the mean age-frequencies among selected year classes, Z=1.48, by regression (R^2=0.99+).

Estimates of M, q, and F. No estimates were possible because the annual effort expended is unknown. Pacific cod which spawn at Nanoose spend the rest of the year elsewhere, and in some cases are subjected to appreciable fishing effort.

Gulf Islands

Twenty-two years of usable age-frequency data were available for Pacific cod landed from MSA 18 (representing Gulf Islands) during January-March 1954-84 (Table 15). No samples were collected during 1963, and 1980-84, and length-frequency samples were deemed too small in 1968 (N=137), 1972 (N=169), and 1973 (N=160) (Foucher and Giudici 1985, Appendix table 4). Age-frequencies (nos./h) for MSA 17-S, by quarter-year, are contained in Appendix table 4; and for Quarters II-IV for MSA 18 in Appendix table 5.

Age-frequencies for six year-classes were deemed usable for computing mortality rates -- 1952-54, 1956, 1961, and 1973 (Table 16). The remainder were deemed unsatisfactory due to missing or unrealistic data.

Estimates of Z. Three estimates of Z were obtained, based on age-classes 3-6 (Table 12). From the mean age-frequencies among years, Z=1.11, by regression (R^2=0.99+). Among selected year-classes, $\bar{Z}$=1.28 (C.V.=32%); and from the mean age-frequencies among selected year classes Z=1.41, by regression (R^2=0.99+).

Estimates of M and q. Regressing Z on mean annual effort, among year-classes, yielded M=2.18, and $q=1.03 \times 10^{-4}$ (R^2=0.073). These estimates were rejected as unrealistic. Probable cause of the poor estimates was the narrow range of mean annual effort -- 1251-1849 h.

Estimates of F. Since no acceptable estimate of M or q was obtained, F could not be estimated from MSA 18 data. Using the MSA 14 estimate of q (1.373×10^{-3}), the values of $F=q\bar{E}$ among year-classes ranged from 1.72 (1961 year-class; Z=2.08) to 2.54 (1952 year-class; Z=1.67). All were deemed unacceptable.

MSA 19

Fourteen years of usable age-frequency data were available for Pacific cod landed from MSA 19 during October-December 1954-84, viz., 1959-60, 1964-65, 1970, 1975-79, and 1981-84 (Table 17). Age-frequency data for 1980 were rejected because the length-frequency sample was too small (N=120; Foucher and Giudici 1985, Appendix table 5). No samples were collected in the remaining missing years. Age-frequency data for the other three quarter-years are contained in Appendix table 6.

Age-frequency data were deemed usable for three year-classes -- 1973, 1974, and 1979 (Table 18).

Estimates of Z. Three estimates of Z were obtained based on age-classes 2-5 (Table 13). From the mean age-frequencies among years, Z=1.26, by regression (R^2=0.99+). Among selected year-classes, $\bar{Z}$=1.63 (C.V.=28%); and from the mean age-frequencies of selected year classes, Z=1.49 by regression (R^2=0.98).

Estimates of M, q, and F. No estimates were possible, because the annual effort expended is unknown. Pacific cod are seasonal, rather than year-round, residents of MSA 19, and the effort expended on them elsewhere is unknown.

MSA 20

Two years of age-frequency data were deemed usable for Pacific cod landed from MSA 20 during January-March 1954-84, viz, 1966 and 1982 (Appendix table 7). Data for 1978-80 were deemed unrealistic, and no length-frequency samples were collected for the remaining years.

Estimates of Z. Two estimates of Z were computed, both based on within-year, age-frequency data for ages 3-6. For 1966, Z=1.16, by regression (R^2=0.91); and for 1982, Z=1.32 (R^2=0.93).

Estimates of M, q, and F. No estimates were possible.

Summary

Estimates of Z were lower for the seasonally-exploited resident stocks in MSA 14 (1.03-1.34) and the Gulf Islands (1.11-1.41) than for the

seasonally exploited itinerant stocks at Nanoose (1.35-1.50) and MSA 19 (1.26-1.63), which are exploited elsewhere at other times in the year.

Among methods, the Z estimates based on mean age-frequencies among years were consistently lowest, and probably provided a more reasonable estimate of mean Z during 1954-85. This is due to the bias introduced by selected year-classes. Selection of each year-class requires usable LPUEs in four consecutive years as the year-class passes through age-classes 3-6 (or 2-5). Only the relatively stronger year-classes tend to qualify since successful sampling is directly related to quantities landed. Stronger year-classes tend to attract more effort, and hence a larger F, than weaker year-classes.

Unfortunately "acceptable" estimates of M (0.59), q (1.373×10^{-3}), and F (0.45-0.75) were only obtained for the cod stock in MSA 14, and these are somewhat doubtful because of the weak regression (R^2=0.32).

A confounding factor in the computations of mortality rates is the reliability of LPUE. For MSA 19, LPUE does not appear to reflect abundance very accurately. Furthermore, the use of January-March landing statistics is in itself subject to question, based on the results of analyses of landing statistics for grounds off southwest Vancouver Island (Area 3C) and in Hecate Strait (Areas 5C and 5D). There, LPUEs for January-March did not reflect stock abundance, presumably due to the behaviour of spawning fish (Westrheim and Foucher 1985b).

The only previous estimates of Z, M, and F were undertaken by Ketchen (1961b), for Nanoose during 1956-60. His estimates of Z were 1.27-1.58 (length-frequency method) and 1.46-1.77 (tagging data), compared with 1.35-1.50 for the current study, at the same location. He estimated F=0.39 and M=1.29, based on tagging data. Interestingly, the tagging data suggested that M increased with age. The current study had no estimates of M and F for Nanoose, but estimated M=0.59 and F=0.45-0.75 for the nearby stock in MSA 14.

Previous estimates of von Bertalanffy growth parameters were undertaken by Ketchen (1961a) and Westrheim (1982). The former utilized length-frequency modes and tagging results to estimate L_∞=72.8-77.4 and K=0.56-0.77. The latter utilized tagging data (Munro 1982) to estimate L_∞=86 cm and K=0.447. Comparable estimates in the current study were L_∞=85.4, K=0.387, and t_0=-0.01.

STOCK ASSESSMENTS

It is now evident that a number of Pacific cod stocks inhabit Georgia and Juan de Fuca straits, although none is entirely isolated from the others. In this study we have delineated four stocks of sufficient size to warrant assessment -- MSA 14, Nanoose (17-N), Gulf Islands (17-S and 18), and MSA 19.

MSA 14

The fishery in MSA 14 exploits seasonally a cod stock resident year-round. Landing statistics suggest that abundance has fluctuated moderately, without trend, during 1954-84. Zenith "plateaus" occurred in 1954-63 and 1975-82, the latter somewhat higher. Since 1982, abundance has declined sharply, but has not yet reached the nadir of 1965-69.

Estimated mean value of Z during 1954-82 was 1.03, and for selected year-classes during 1952-64, 1.24 or 1.34. Estimated mean value of M during 1952-64 was 0.59, and hence by substraction, corresponding estimates of $\bar{F}$ were 0.44 during 1954-84, and 0.65 or 0.75 during 1956-64. If q is constant, and our estimate (1.373×10^{-3}) is reasonable, then mean F was 0.89 (0.81-0.97) during 1954-60 when mean annual effort was 645 h (594-707); and 0.36 (0.31-0.46) during 1979-84 when mean annual effort was 268 h (225-319). The high level of effort during 1954-60 may have been excessive, as effort was sharply reduced thereafter, and has remained below 400 h/y since then, except for three years -- 1963-64, 1970-71, and 1972-73. At 400 h, F = 0.54, which may mark a "safe" upper limit.

In summary, the Pacific cod stock in MSA 14 is successfully sustaining itself, and current fishing rates do not appear to be a threat to the stock.

Nanoose (MSA 17-N)

The fishery at Nanoose exploits a seasonal, itinerant cod stock, which is also exploited elsewhere during the rest of the year. Landing statistics indicate that abundance fluctuated substantially, without trend, during 1954-78, but has declined to a low level in 1975, and remained there through 1985.

Estimated mean value of Z during 1954-79 was 1.35, and for selected year-classes, 1.48 or 1.50. These estimates were substantially larger than those for the MSA 14 stock, and may well reflect the additional fishing mortality sustained elsewhere.

No estimates of M, q, or F were possible with the available data from Nanoose, because total annual effort expended on these fish is unknown.

The available evidence from landing statistics and mortality rates does not indicate that the decline in cod abundance at Nanoose was due necessarily to the local fishery. Five other factors have been considered -- fisheries elsewhere; decline in prey abundance; increase in predator abundance; hydrography; and military installations.

Fisheries elsewhere. Principal fisheries elsewhere which might have affected abundance of cod at Nanoose were those in the southeast Strait of Georgia (MSAs 29, 80, 82, 83), Gulf Islands (MSAs 17-S and 18) and MSA 14, based on tagging results (Westrheim 1982, Table 7). Within the southeast Strait, landings from MSA 80 predominate. Indeed, MSAs 80 and 86, at

near-equal proportions, provided 90% of the cod landings from Area 4A. Gosho (1976) estimated the minimum contributions of MSA-80 cod to the Nanoose spawning "stock" at 18.8% in 1967, 29.0% in 1968, and 23.2% in 1971.

January-March landings of Pacific cod from the three important contributory "stocks" exhibited moderate to substantial reciprocal relationships with landings from Nanoose during 1971-81 (Fig. 9). The relationship was particularly strong with the Gulf Islands stock, whose landings during 1972-78 rose from 214 t to 493 t, while Nanoose landings fell from 250 t to 15 t. Apparently, Pacific cod were shunning the Nanoose trawling grounds.

Decline in prey abundance. Principal prey of Pacific cod occupying the Nanoose grounds is Pacific herring, based on stomach contents of cod sampled from landings for length and sex (Table 19). During 1951-79, 16 length-frequency samples were collected in which the sampler recorded the stomach contents. Herring was the principal species noted in all 16 samples.

Nanoose Bay is an important spawning ground for Pacific herring in the Strait of Georgia (Haegele and Fitzpatrick 1983). During 1971-78, herring abundance was not less, nor declining, as the roe fishery yielded 274-9356 t/y ($\bar{x}$=3130) -- 9376 t in 1978, and 2752-4378 during 1972-75.

Increase in predator abundance. Steller sea lions (Eumetopias jubatus) prey on Pacific cod in the Gulf of Alaska (Pitcher 1981), and probably do likewise in British Columbia waters, where opportunities permit. During 1972-84, the numbers of Steller sea lions wintering off southeastern Vancouver Island increased from 74 in 1972 to 983 in 1982, then declined to 328 in 1984 (Bigg 1985, Table 8). Of special interest was a new haulout on Ada Island, ~2 nautical miles northeast of the Nanoose trawling ground, first occupied in 1973. There, annual counts rose rapidly from ca. 40 in 1973 to ca. 400 in 1977; held steady at 300-400 during 1977-81; then declined sharply to ca. 100 in 1983 (op. cit., Fig. 10). The haul-out was occupied from November to late May. Co-habitants at Ada Island, and elsewhere off southeastern Vancouver Island, were California sea lions (Zalophus californianus), albeit in lesser (and not reported) numbers. Presumably they too are potential cod predators.

Diet analyses of these sea lions are incomplete at this date (M. Bigg, pers. comm.), and hence the degree of predation, if any, on the Nanoose cod is unknown. Perhaps even the nearby presence of these large mammals may have been an inhibiting factor.

Hydrography. Nanoose Bay contains a layered, dynamic water mass, partly separated from the Strait of Georgia by an 18-m sill (Herlinveaux et al. 1966). The water mass is readily affected by external factors which alter the surface and sub-surface flows. Prolonged periods of stratification can produce anoxic conditions in the bottom layer of the bay (R. H. Herlinveaux, pers. comm.). The sudden outflow of such H_2S-rich water would likely kill, or drive off, any fish occupying the trawling grounds immediately

outside the bay. Two factors which can cause such an outflow are a sudden decrease in surface-water salinity in Georgia Strait accompanied by southerly wind, and sub-surface spill of cold, saline water into Georgia Strait, from the Pacific Ocean, over the sills at the Strait's southern boundary.

Low-salinity "events" (salinity <26°/$_{oo}$) in surface water at Entrance Island Lighthouse (12 miles southeast of Nanoose Bay) are reflected in Nanoose Bay 1-2 days later (Herlinveaux et al. 1966). Results are a retention of surface waters in the Bay, and an increased sub-surface outflow. A compilation of such "events" at Entrance Island Lighthouse during January-March 1957-84 did not yield any relationship to cod landings from Nanoose (Table 20).

Sub-surface inflow into Georgia Strait over sills at its southern boundary spreads out, at depth, throughout the Strait (Herlinveaux and Giovando 1969). A recent discovery is that this water mass can move over the sill into Nanoose Bay and displace the resident bottom water (Herlinveaux pers. comm.). Recent studies (as yet unpublished) have identified such "events" which have occurred during February-March, in 1972, 1975, 1977, and 1979 (the "worst"). Such events would not be detectable in surface-water temperatures or salinities at Entrance Island Lighthouse.

In summary, sub-surface outflows of H_2S-rich bottom water from Nanoose Bay may have been a factor in the diversion of Pacific cod away from Nanoose, but there is as yet no evidence available to support such a hypothesis.

Military installations. Eastward of Nanoose Bay, electronic devices were installed on the bottom during 1964-72 to service a naval test range (Herlinveaux pers. comm). However, these devices were installed in deep water (>150 fath) and are listening devices, which do not emit any signal. The installations do not appear to be a factor in the 1972-84 decline of cod landings from Nanoose.

Summary. The decline in cod landings from Nanoose appears to be due to diversion elsewhere rather than depletion, based on the reciprocal relationship between landings from Nanoose and landings from other nearby locations. The causes of this phenomenon have not been determined by this study. Of the four potential factors considered, decline in prey (herring) abundance and military installations have been eliminated. Increase in predator (sea lion) abundance, and hydrography, remain for consideration, at least until completion of studies currently underway, viz., diet of sea lions occupying nearby Ada Rocks, and the effect of sub-surface hydrographic "events" in Georgia Strait on circulation in Nanoose Bay.

Gulf Islands (17-S and 18)

The fishery in the Gulf Islands, like that in MSA 14, exploits seasonally a cod stock largely resident year-round. Landing statistics indicate that abundance has fluctuated moderately, without trend, during 1954-84. Abundance during 1971-78 was generally higher than during 1954-70.

Zeniths and nadirs were not well delineated. Since 1978-79, abundance has declined irregularly, but not substantially.

Estimated mean value of Z among years, during 1954-79, was 1.11, and for selected year-classes, 1.28 or 1.41 -- all similar to those in MSA 14.

The lack of acceptable estimates of M and q precluded obtaining estimates of F. Furthermore, the disparity between effort values for MSAs 14 and 18, precluded use of q from MSA 14 to estimate F in MSA 18.

In summary, the cod stock in MSA 18 is successfully sustaining itself at Z values of 1.11-1.41. The age composition of the landings has remained relatively constant during 1954-84.

MSA 19

The fishery in MSA 19 exploits an itinerant, seasonal stock, whose origin is probably the offshore grounds in Area 3C. The spectacular rise and fall in cod abundance during 1974-84 has been attributed to the anomalous behaviour of mature herring enroute inshore to spawn in the Strait of Georgia.

Estimated mean value of Z during 1974-84 was 1.26, and for selected year-classes, 1.49 and 1.63 -- similar to Nanoose, and higher than those for MSA 14 and the Gulf Islands. As with Nanoose, the higher rates probably reflect the effect of fishing on these cod elsewhere during the remainder of the year.

No estimates of M, q, and F were possible with the available data.

The fishery in MSA 19 is exploiting a temporary, seasonal concentration of Pacific cod. Conventional stock assessment techniques are simply not applicable. Hence, no stock assessment is offered.

Summary

Of the four important stocks of Pacific cod in Area 4B, none appears to be adversely affected by the fishery. However, the resident MSA 14 stock may have been adversely affected during 1954-60 by relatively high levels of effort. The near-exponential decline in abundance of the itinerant stock at Nanoose, after 1971, appears to be due to diversion of the cod elsewhere, the cause(s) of which is (are) unknown. The resident cod stock in the Gulf Islands exhibits no substantial trend in abundance, and the itinerant MSA 19 stock appears to be a transitory "event", caused by anomalous behaviour of herring enroute to spawning grounds in Area 4B.

A sharp decline in abundance after 1981 was noted in all British Columbia stocks, including those offshore (Westrheim and Foucher 1985b). This phenomenon has been generally attributed to coastwide adverse environmental factors.

YIELD PER RECRUIT (YPR)

The foregoing stock assessments revealed that the Pacific cod in Area 4B appear to be successfully sustaining total instantaneous mortality rates as high as 1.41 for resident stocks, and 1.63 for itinerant stocks. Three questions remain to be answered which deal with optimizing yield, catch profitability, and processing profitability. The former two are considered in this report, but the latter one is beyond the scope of the present report.

Yield

Of the two values of M employed, 0.6 was based on the estimate (M=0.59) derived for MSA 14, while 0.4 was arbitrarily selected.

Maximum yield. For M=0.4, YPRs for the selected values of mesh size and fishing mortality rate (F) are given in Table 21 for the two values of minimum commercial size (MCS=41 and 46 cm). Corresponding yield isopleths are shown in Figures 10 and 11. For each mesh size, YPRs exhibited a maximum value which varied directly with mesh size and F, but inversely with MCS. At MCS=41 cm, maximum yield was 817 g, achieved with 8.0" mesh, and F=1.2. At MCS=46 cm, the corresponding value was 810 g, with 8.0" mesh and F=1.2. Among F values, maximum values of YPR varied directly with F, but exhibited little relationship to mesh size, except at low values of F.

For M=0.6, corresponding values of YPR are shown in Table 22, and isopleths in Figures 12 and 13. General results were the same as those for M=0.4, but maximum values of YPR were smaller. If MCS=41 cm, maximum YPR is 469 g, achieved with 7.0" mesh, at F=1.2. If MCS=46 cm, maximum YPR is 442 g, with 7.5" mesh, at F=1.2.

In summary, at each of the four combinations of natural mortality rate and minimum commercial size, maximum values of YPR were achieved at relatively large mesh sizes (7.0-8.0") and fishing mortality rate (F=1.2). Neither the large mesh sizes nor the high fishing mortality rate was realistic. The optimum mesh size is impractical for the mixed-species fishery in Area 4B, and will be discussed in the following sub-section (Mesh selection). The optimum fishing mortality rate is excessive with respect to trawling cost, and will be discussed in the following section (Catch Profitabilility).

Mesh selection. Mesh selectivity studies were undertaken during January 1959 in Area 4B, and were aimed primarily at English sole (Parophrys vetulus) (Ketchen 1961b). Based in part on the results of these studies, mesh regulations were imposed in 1962 on trawl nets used in Area 4B, which are still in effect. Minimum mesh size (internal measure) applied only to the last 50 meshes of the cod-end, and varied with netting material -- 4.75" (121 mm) for manila, 4.5" (114 mm) for cotton, and 4.25" (108 mm) for synthetics (Forrester and Ketchen 1963, p.70). Manila and cotton have been replaced now by synthetic materials.

During 1945-77, 70.8% of the trawl-caught groundfish landed from Area 4B, for human consumption, consisted of Pacific cod (52.3%) and English sole (18.5%) (Westrheim 1980). Minimum commercial size for English sole was ≈ 12" (30.5 cm) (Ketchen 1961b, Fig. 3), and the modal size of fish landed for sale was ≈ 32 cm (Forrester and Ketchen 1963, Figs. 31 and 32). Based on Forrester's (1974) length-girth formula (L=1.3 G + 1.6), the lengths at 50% selection were 37.2, 43.2, and 55.2 cm, respectively, for mesh sizes of 6", 7", and 8". Thus, even a 6" mesh would be unsuitable for catching marketable English sole. In contrast, the lengths at 50% selection (for cotton mesh) were 28 cm for 4.0" mesh, 32 cm for 4.5" mesh, and 36 cm for 5.0" mesh (Ketchen 1961a).

Catch Profitability

Indices of catch profitability (YPR/F) were maximal at F=0.2 in all four combinations of natural mortality rate and minimum commercial size -- 2515 (M=0.4, MCS=41 cm); 2405 (M=0.4, MCS=46 cm); 1285 (M=0.6, MCS=41 cm); and 1110 (M=0.6, MCS=46 cm). However, none of these maxima was realistic because: (1) the low value of F meant a substantial reduction in total landings; and (2) three of the four maxima required mesh sizes of 6.5-8.0".

A more realistic approach was made by calculating YPR/F for maximum YPR values per selected mesh size (Table 23). For M=0.4, maximum YPR/F was 1415 (F=0.4, 4.5" mesh) for MCS=41 cm, and 1463 (F=0.3, 4.0" mesh) for MCS=46 cm. At MCS=41 cm, YPR/F was 3% smaller, but YPR was 29% larger, hence the 41-cm MCS was superior. For M=0.6, maximum YPR/F was 514 (F=0.7, 4.5" mesh) for MCS=41 cm, and 598 (F=0.4, 4.0" mesh) for MCS=46 cm. At MCS=41 cm, YPR/F was 14% smaller, but YPR was 51% larger. Again, the 41-cm MCS was superior.

Maximum values of YPR/F were achieved over a narrow range of mesh sizes (4.0-4.5"), but their values varied substantially with respect to values of natural mortality rate -- 1415 and 1463 for M=0.4; 514 and 598 for M=0.6.

The current fishery for Pacific cod in Area 4B appears to be close to the maximum YPR/F value of 514 -- M=0.6, F=0.7, MCS=41 cm, and mesh size=4.5". Actually, the minimum mesh size in effect is 4.25", but 0.25" of mesh size is probably well within the error range of the data.

Summary

Maximum YPR values required excessively large values for F and mesh size, at least at M=0.4 and 0.6, and MCS=41 and 46 cm. Maximum YPR/F values required excessively small values of F, and for the most part excessively large mesh sizes, together with a substantial reduction in total landings. YPR/F values based on YPR maxima by mesh size were maximal at realistic mesh sizes, at both values of M and MCS. For conditions closest to the current fishery, maximum YPR/F=514, at M=0.6, MCS=41 cm, F=0.7, and mesh size=4.5". If M=0.4, no satisfactory maximum YPR/F can be achieved at F=0.7, because the associated mesh size is too large (>5.5") for the mixed-species fishery.

SUMMARY AND CONCLUSIONS

Four important stocks of Pacific cod were delineated in Georgia and Juan de Fuca straits (Area 4B), primarily based on the results of Canadian and U.S. tagging experiments during 1954-79, inshore (Area 4A and 4B) and offshore (Areas 3A, 3B, and 3C). All four stocks are exploited seasonally in Area 4B -- prinicipally October-March. Two are year-round residents in their respective locations (MSA 14 and Gulf Islands), while the other two are itinerant, seasonal residents (Nanoose and MSA 19).

Standardized landing statistics revealed variable exploitation histories among stocks, but abundance fluctuations were attributed to natural, rather than fishery, causes. The resident stocks in MSA 14 and the Gulf Islands exhibited near-synchronous fluctuations in landings and LPUEs, without evident trend. Abundance of both stocks declined sharply during 1980-84, a coastwide phenomenon for B.C. cod stocks attributed to natural factors. The itinerant stock at Nanoose exhibited a substantial decline in abundance after 1971 which was attributed to diversion, for unknown cause(s).

Estimates of total mortality rate (Z) were lower for the resident stocks in MSA 14 (1.03-1.34) and the Gulf Islands (1.11-1.41), than for the itinerant stocks at Nanoose (1.35-1.50) and MSA 19 (1.26-1.63) which were exploited elsewhere at other times of the year. Estimates of natural (M) and fishing (F) mortality rates were only obtainable for the stock in MSA 14 -- M=0.59 and F=0.45-0.75.

Stock assessments, based on standardized landing statistics and mortality rates, concluded that the four important cod stocks in Area 4B were not adversely affected by the fishery, except perhaps the MSA 14 stock during 1954-60.

Yield per recruit (YPR) analysis revealed that maximum YPR values required excessively large values of fishing mortality (F=1.2) and mesh size ($\geq$6.5"), at least if natural mortality rate (M) is 0.4 or 0.6, and the minimum commercial size (MCS) is 41 or 46 cm. Maximum catch-profitability indices (YPR/F) required excessively low values of F (0.2), and for the most part, excessively large mesh sizes ($\geq$6.5"). YPR/F values based on maximum YPR values with respect to mesh size were maximal at practical mesh sizes (4.0-4.5"), at both values of M and MCS. For conditions closest to the current fishery, maximum YPR/F=514, at M=0.6, MCS=41 cm, F=0.7, and mesh size=4.5". At MCS=46 cm, maximum YPR/F (598) was 16% larger, but with 34% less yield with mesh size=4.0", and F=0.4.

DISCUSSION

The current study yielded important results with respect to stock delineation, stock assessment, and yield per recruit, most of which corroborated earlier, less detailed analyses.

Stock delineation studies, largely based on results of extensive Canadian and U.S. tagging experiments during 1954-79, revealed four important stocks of Pacific cod in Georgia and Juan de Fuca straits -- two resident year-round and two itinerant and seasonal. The four stocks were sufficiently different, in behaviour, to preclude treating Pacific cod in the study area as a single stock, for stock assessment purposes. The only previous stock delineation study (Forrester and Ketchen 1963) identified only two stocks (MSA 14 and Nanoose-Gulf Islands), based on results of limited Canadian tagging experiments during 1954-59. The MSA 19 fishery was negligible at that time.

Stock assessments of this study, based on standardized landing statistics and landings-at-age data, revealed that, with the possible exception of the MSA 14 stock during 1956-60, abundance fluctuations were deemed to be independent of the fisheries. The five previous analyses of landing statistics, yielded mixed results. Three studies, based on nominal landing statistics from individual management areas (mostly sub-divisions of MSAs in Area 4B) concluded that abundance fluctuations of Pacific cod were independent of the fishery (Forrester and Ketchen 1963; Forrester and Smith 1974; Westrheim 1982). Ketchen (1979) analyzed standardized all-species landing statistics of Area 4B as a whole, and hypothesized that "relatively high fishing effort throughout the 1950s and early 1960s was sufficient to reduce the abundance of foodfish" (including Pacific cod) (op. cit. p. 17). He proposed further analyses to test the hypothesis. Ketchen et al. (1983) reviewed standardized landing statistics for Area 4B as a whole, and stated that "until overfishing can be positively identified, it must be presumed that fluctuations in abundance are predominantly of natural origin" (op. cit. p. 1106). They noted that information on age composition of landings was an important component of the additional data needed for an improved analysis.

Our yield-per-recruit analyses produced maximum values at excessively large mesh sizes (>6.5") and F (1.2), at least if M=0.4 or 0.6, and MCS=41 or 46 cm. Forrester and Ketchen (1963) undertook the only other YPR analysis (Nanoose) employing constant and varying values of M (1.2; 0.6-1.2, increasing with age). They concluded that the optimal age-at-entry was 2.0 y (equivalent to a mesh size of 6.5" according to the current study). Interestingly, their estimated yields were substantially larger if M was increasing with age.

Our YPR/F analyses, roughly incorporating catch costs, suggested that current mesh regulations in Area 4B are reasonably satisfactory, if all parameters employed are also satisfactory. A minimum commercial size of 41 cm (16") is superior to 46 cm (18"). No other YPR/F analysis has been reported.

A number of unsubstantiated assumptions underly these analyses, and at least deserve mention. Three are discussed here -- adequate index of abundance, valid age determination and adequate estimate(s) of natural mortality rate (M).

LPUE was assumed to be an adequate index of abundance, at least for the MSA 14, Nanoose, and Gulf Island stocks, although declining proportions of interviewed landings are a serious threat to the continuing validity of this assumption. Furthermore, Westrheim and Foucher (1985b) reported that on the offshore grounds (Areas 3C, 5A, 5B, 5C, and 5D) LPUE was not a satisfactory index of abundance during January-March, presumably due to the behaviour of cod during the spawning season. Aberrations in the abundance index will also affect landings-at-age data, and subsequently the estimates of Z, M, and F.

Validation of the Foucher-Fournier (1982) age-determination method has not been achieved to date (November 1986). Problems of "slopover" were noted by Westrheim and Foucher (1985b) for analyses of Pacific cod on the offshore grounds. That is, as age increased, members of a strong year-class tended to be assigned to one of the adjacent year classes. The result would be that Z would be overestimated.

Both the absolute value and relative constancy of M are important, particularly to the YPR analysis. The estimate of M=0.6 was based on a rather tenuous regression (R^2=0.32) of Z on effort for the MSA 14 stock. The same methods applied to offshore cod stocks yielded similar estimates of M -- 0.58 in Area 3C; 0.78 in Queen Charlotte Sound (Areas 5A & 5B; an underutilized stock); and 0.65 in Hecate Strait (Areas 5C & 5D) (Westrheim and Foucher 1985b). Hopefully, this estimate is reasonable, and applicable to the other three cod stocks, for which no estimates could be made. If M is not constant after age 1.0, YPR values will be affected. If M increases with age, as suggested by Ketchen's (1961b) tagging data, then our YPRs will be underestimated. Conversely, if M is decreasing, our YPRs will be overestimated.

Unfortunately, the aforementioned assumptions cannot be verified with available information. However, the cod stocks in Area 4B exhibit no symptoms of recruitment overfishing, but the question of growth overfishing (or underfishing) must receive further attention due primarily to the questionable status of our estimate of M.

ACKNOWLEDGMENTS

W. R. Harling, Dr. K. S. Ketchen, and Dr. A. V. Tyler reviewed all, or portions of, the manuscript, and suggested a number of improvements.

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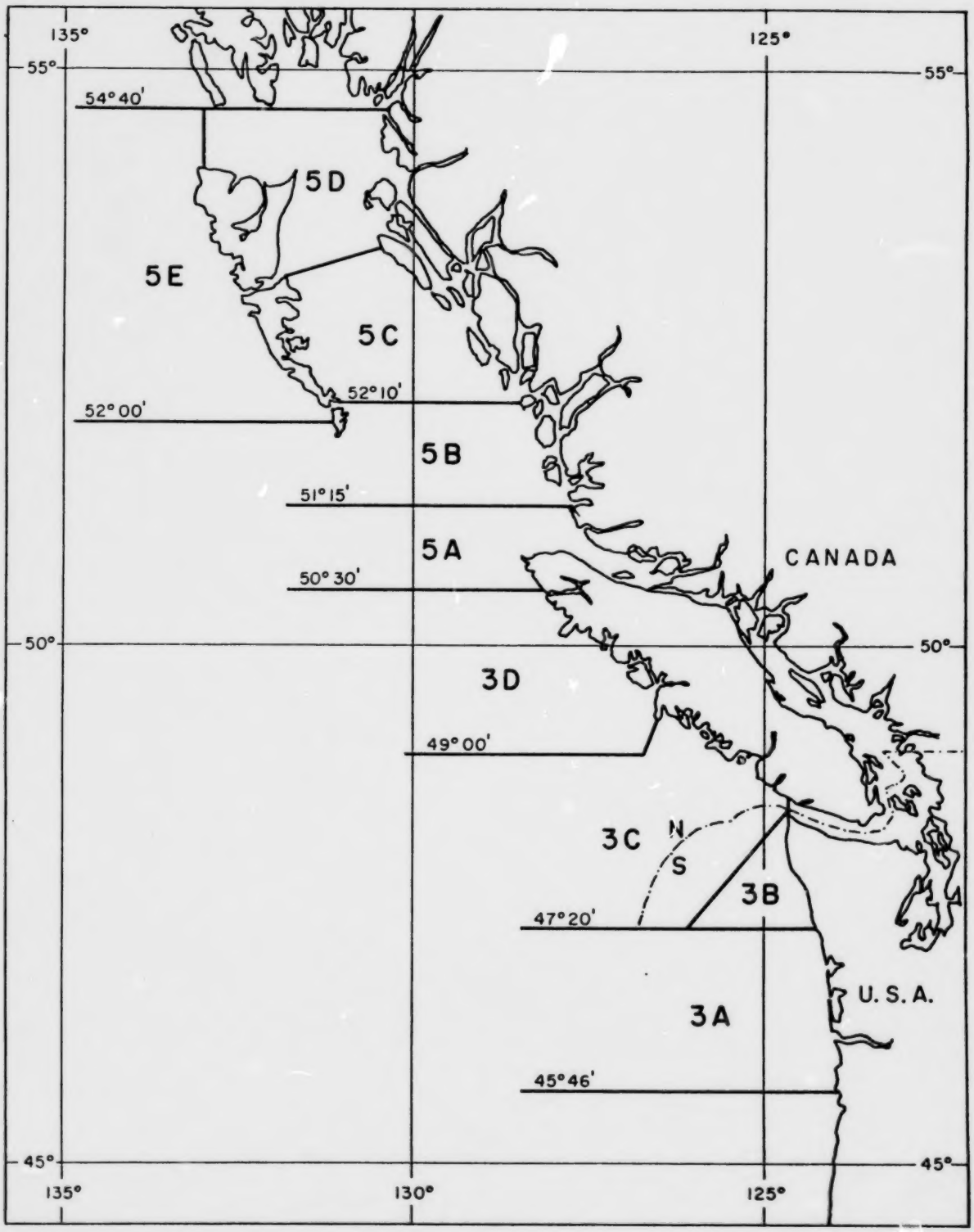

Fig. 1. Major statistical areas off the coasts of British Columbia and Washington State.

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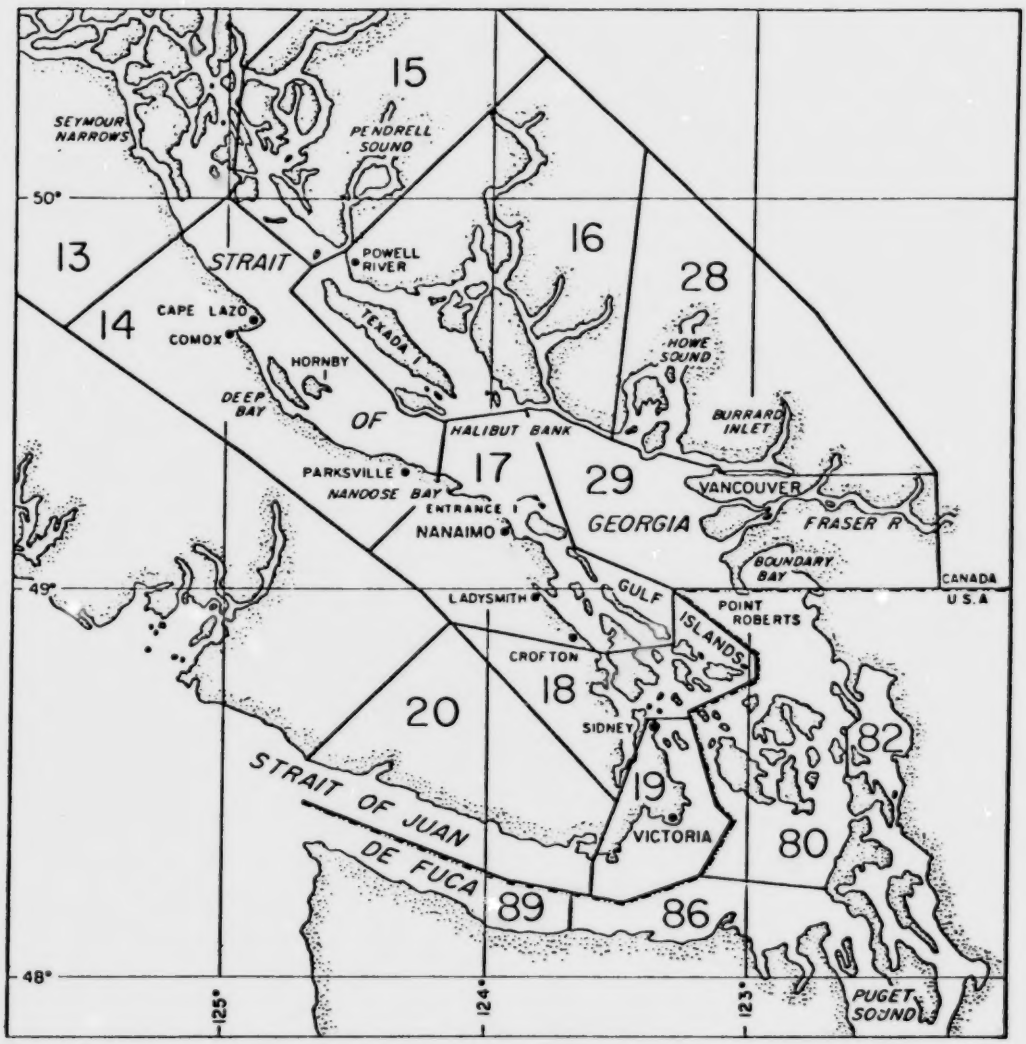

Fig. 2. Minor statistical areas (MSAs) in Area 4A and 4B.

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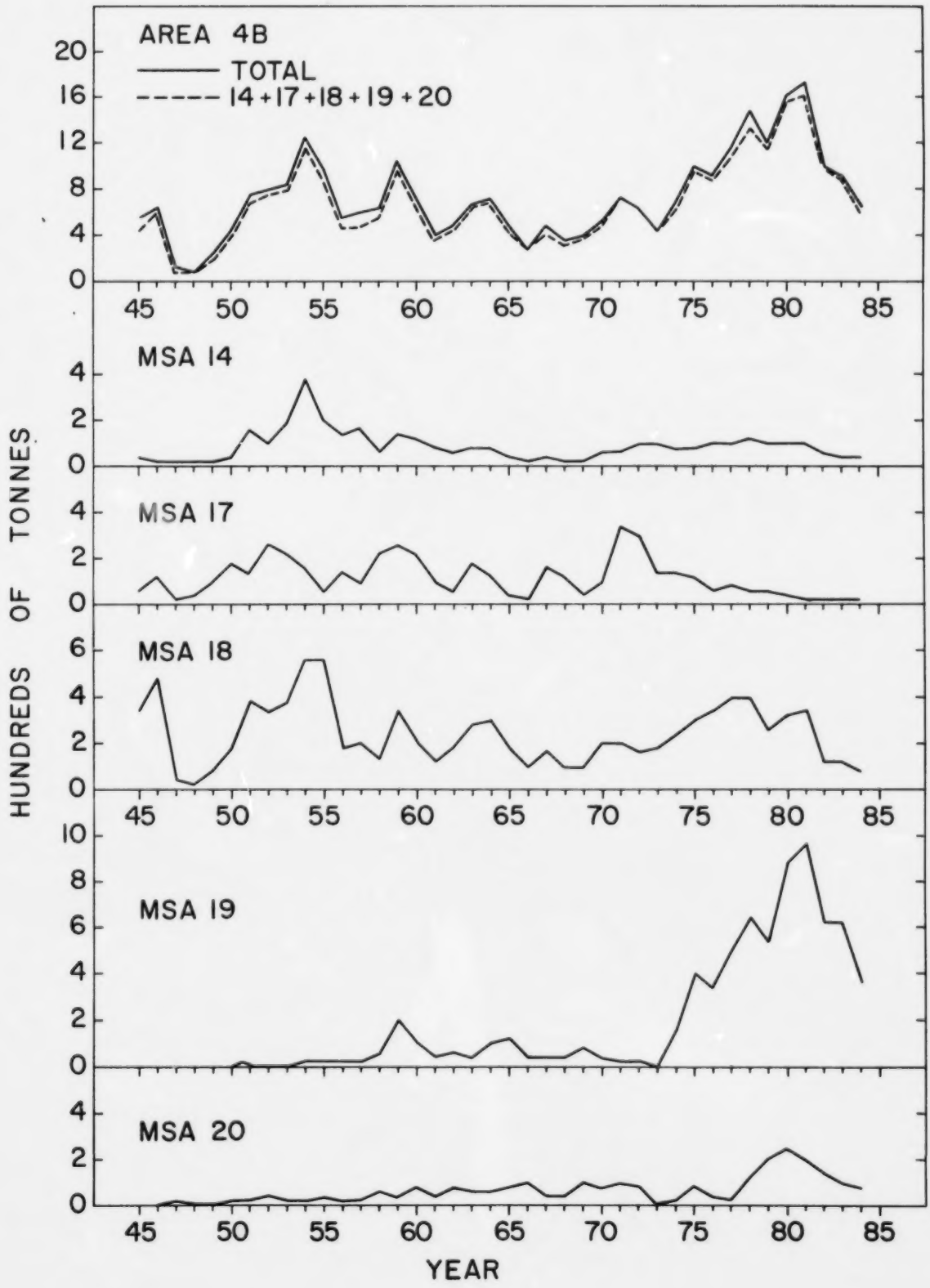

Fig. 3. Annual landings (t) of Pacific cod from Area 4B, and its important MSAs, 1945-84.

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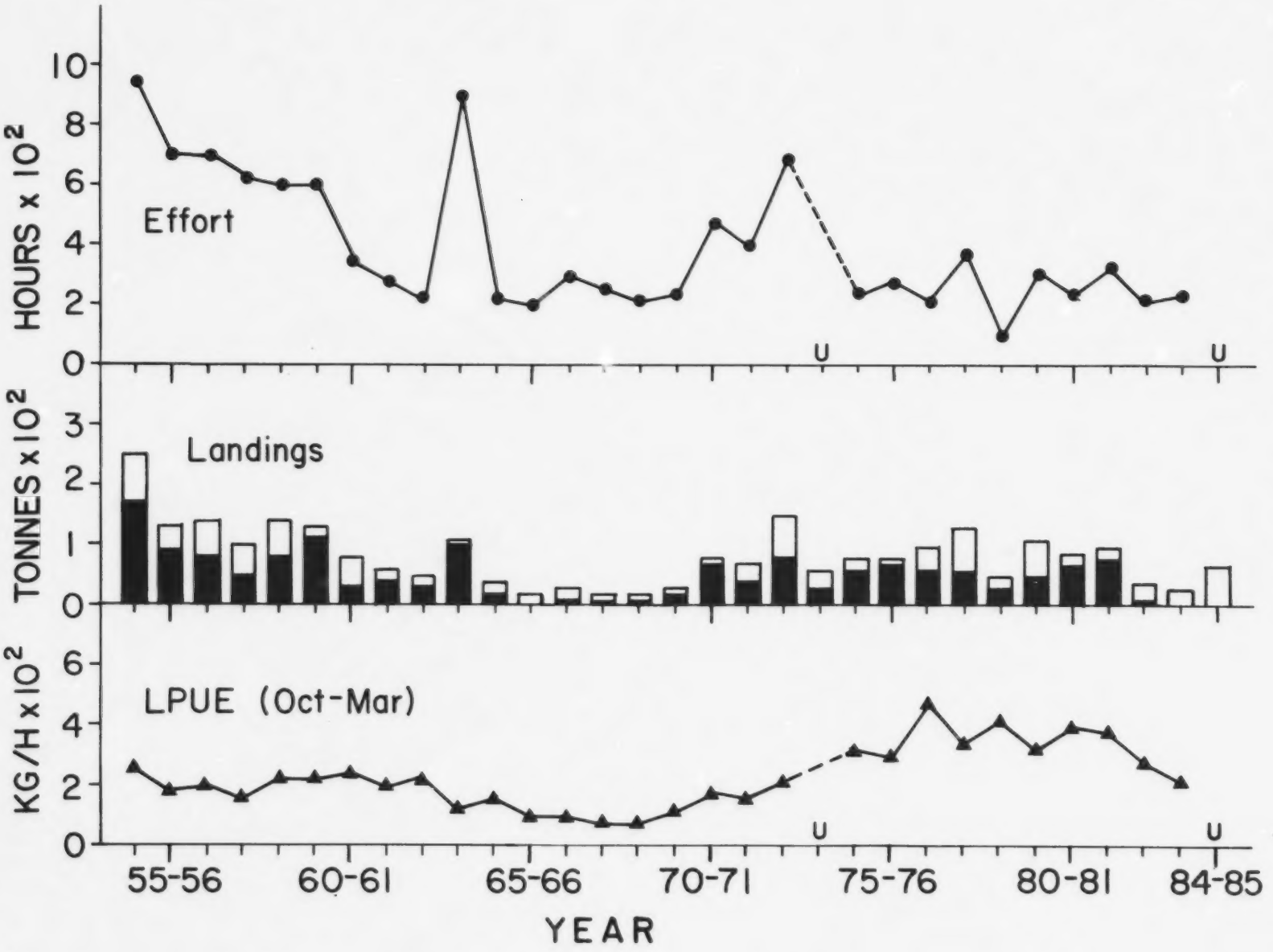

Fig. 4. Standardized landing statistics for Pacific cod from MSA 14, October-September 1954-55 through 1984-85.

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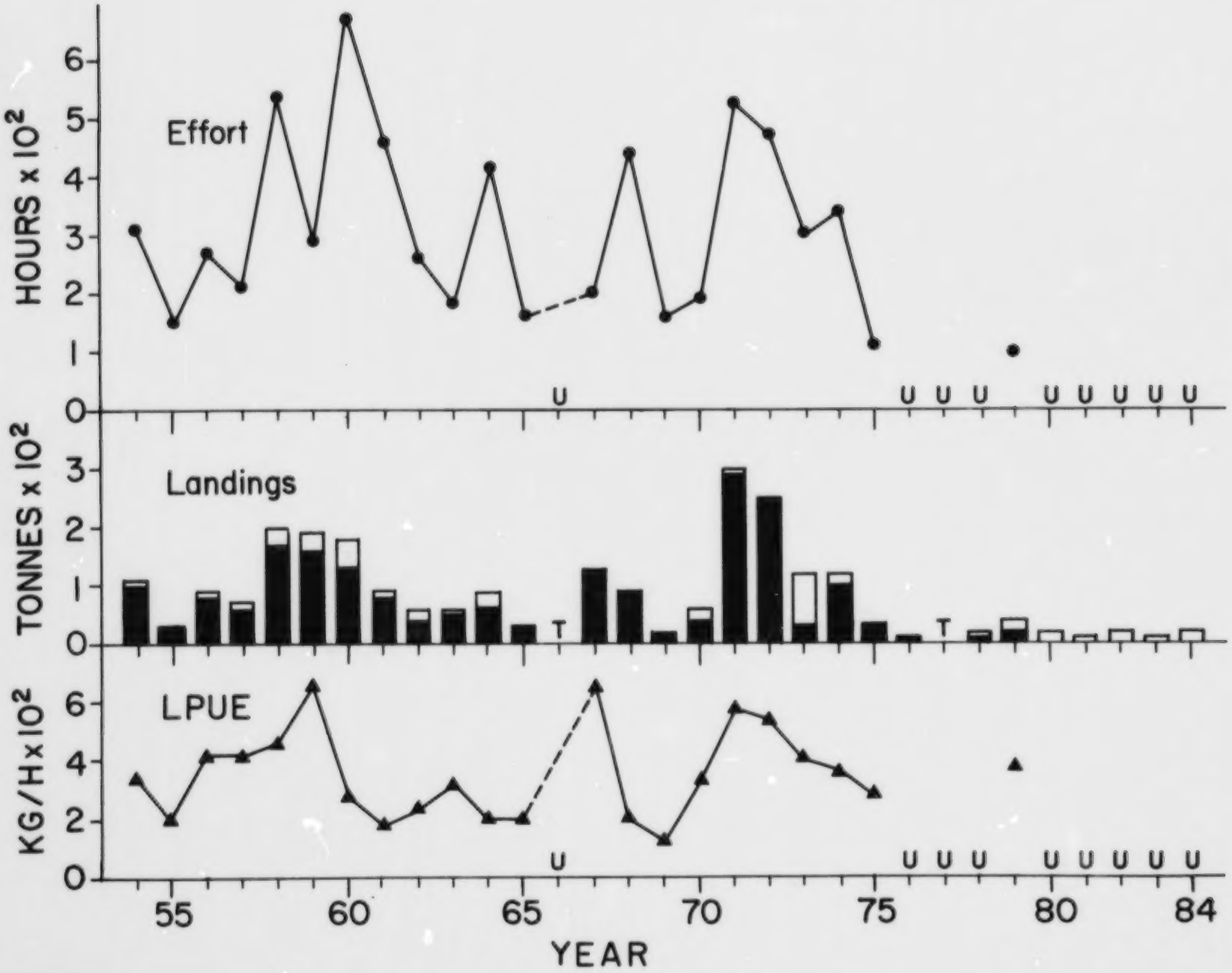

Fig. 5. Standardized landing statistics for Pacific cod from Nanoose (MSA 17-N), January-March 1954-84.

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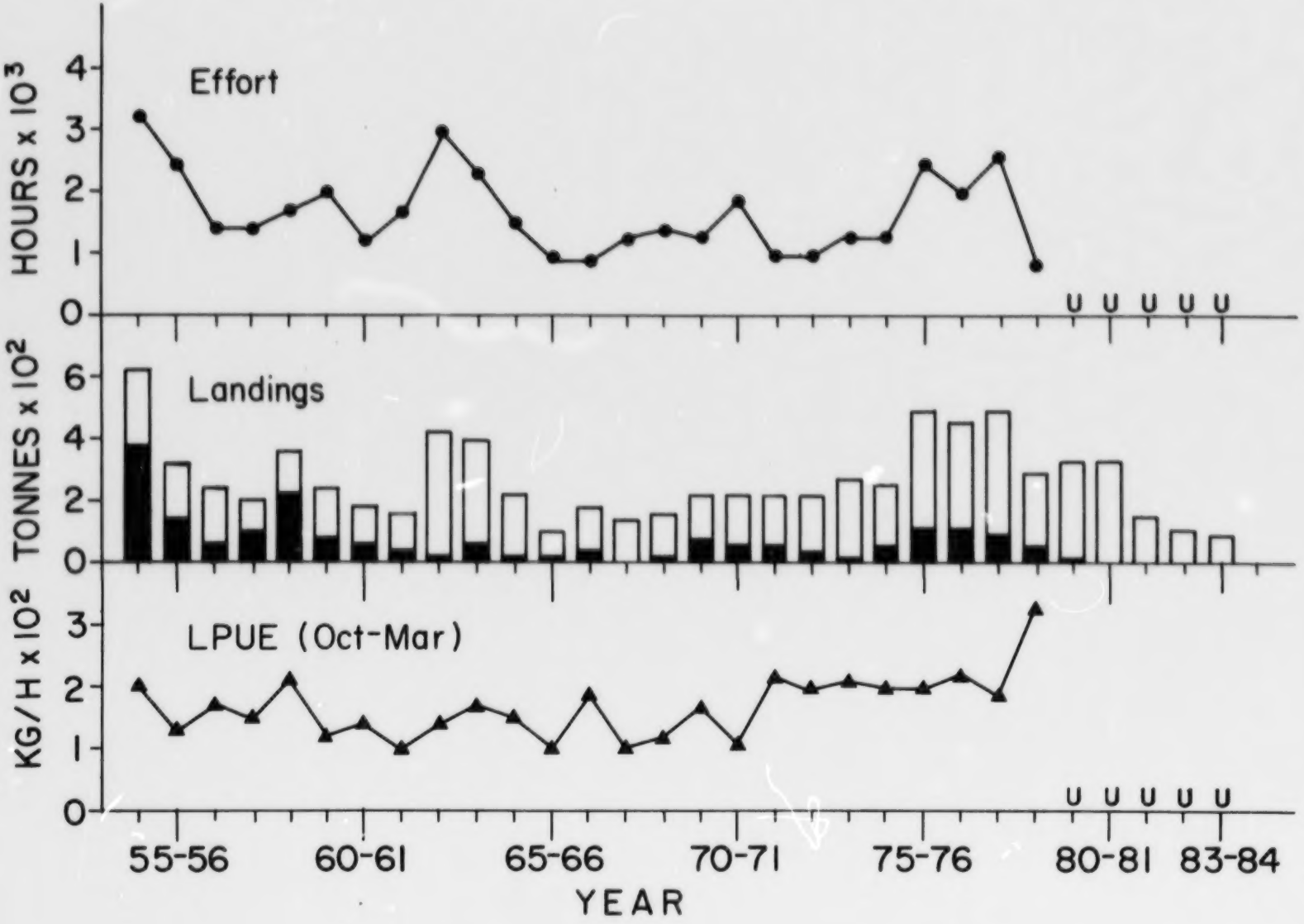

Fig. 6. Standardized landing statistics for Pacific cod from the Gulf Islands (MSAs 17-S and 18), October-September 1954-55 through 1984-85.

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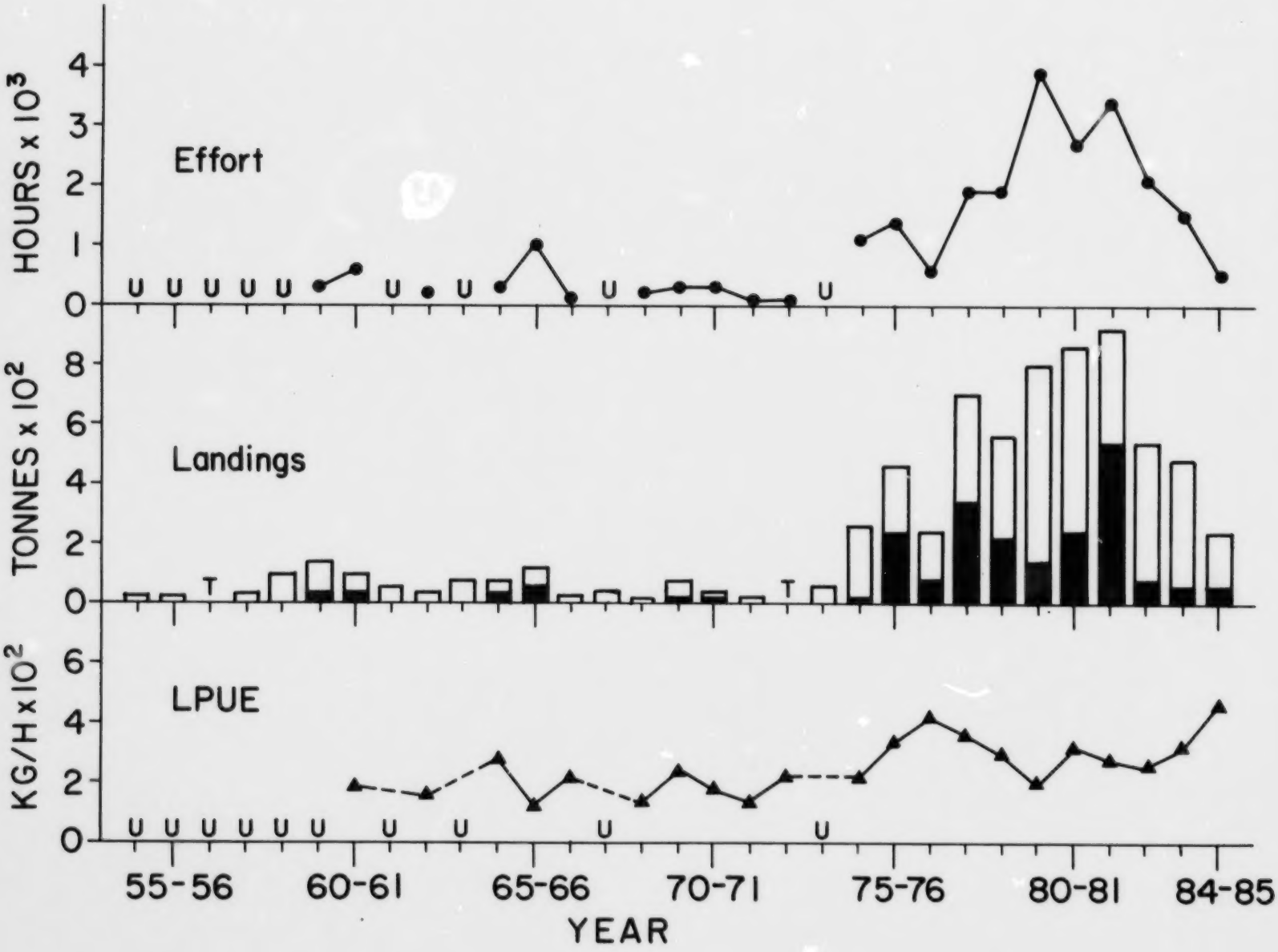

Fig. 7. Standardized landing statistics for Pacific cod from MSA 19, October-September, 1954-55 through 1984-85.

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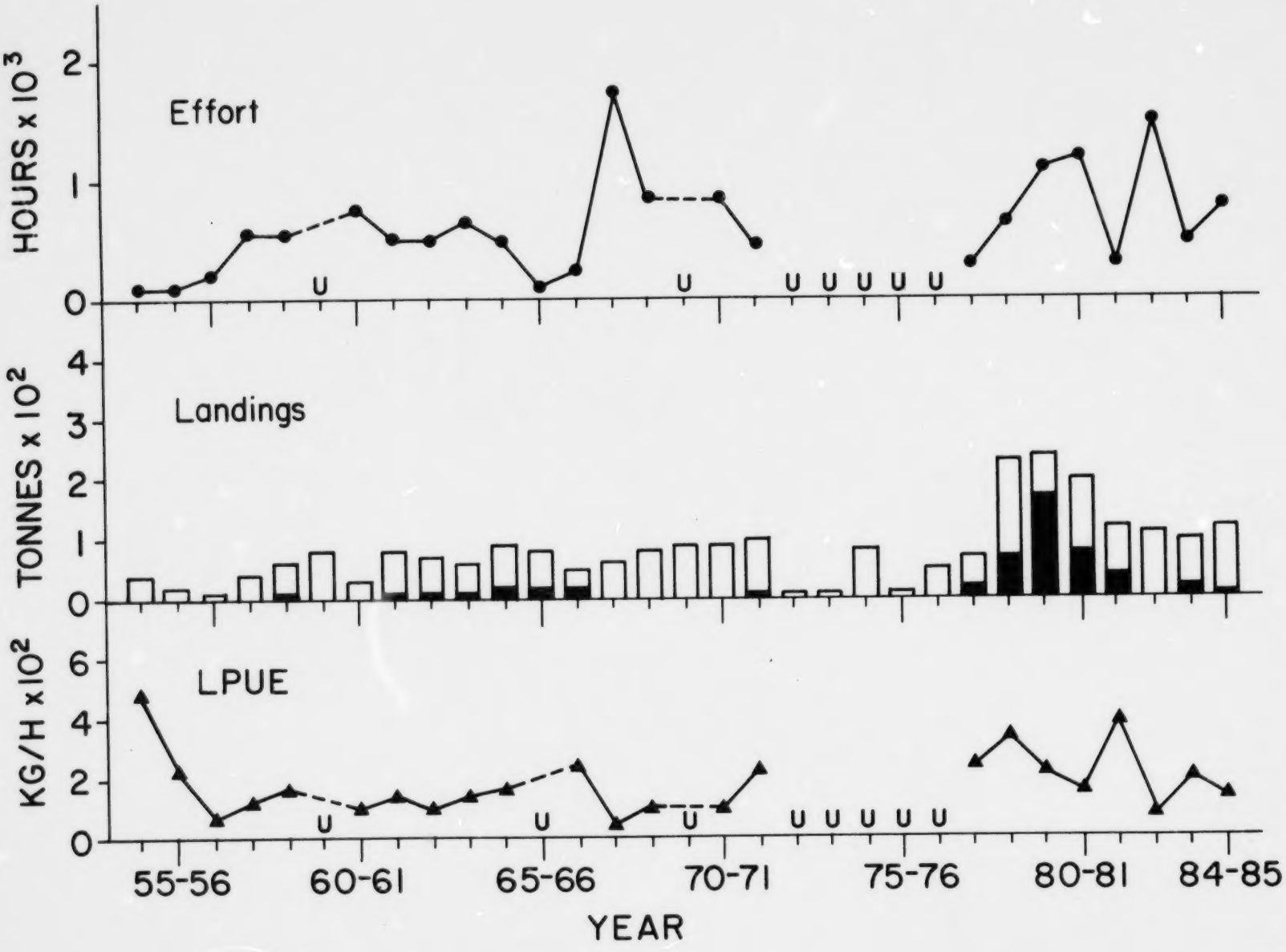

Fig. 8. Standardized landing statistics for Pacific cod from MSA 20, October-September, 1954-55 through 1984-85.

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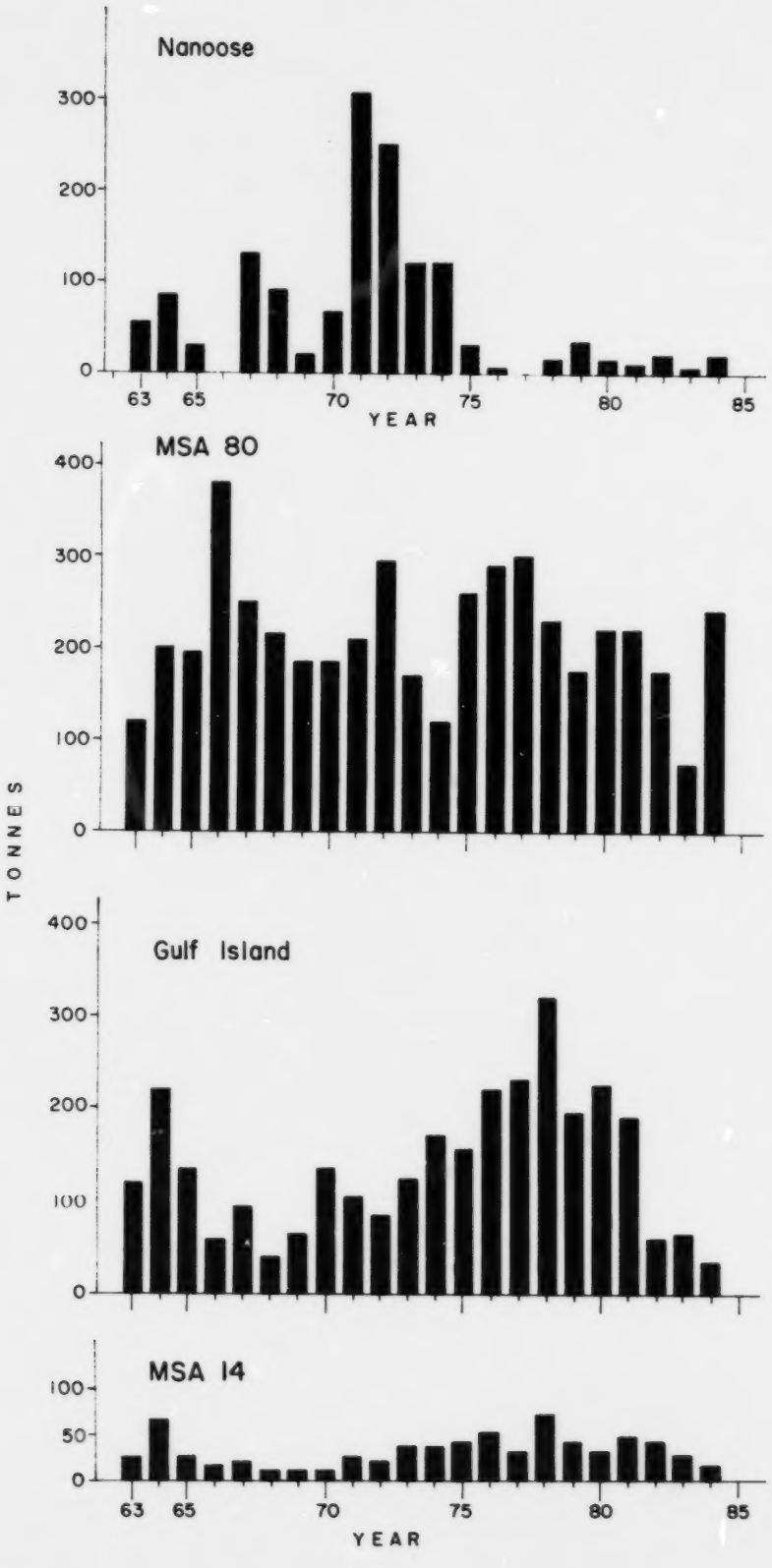

Fig. 9. Annual landings (t) of Pacific cod from Nanoose, and three important contributory "stocks", during January-March 1963-84.

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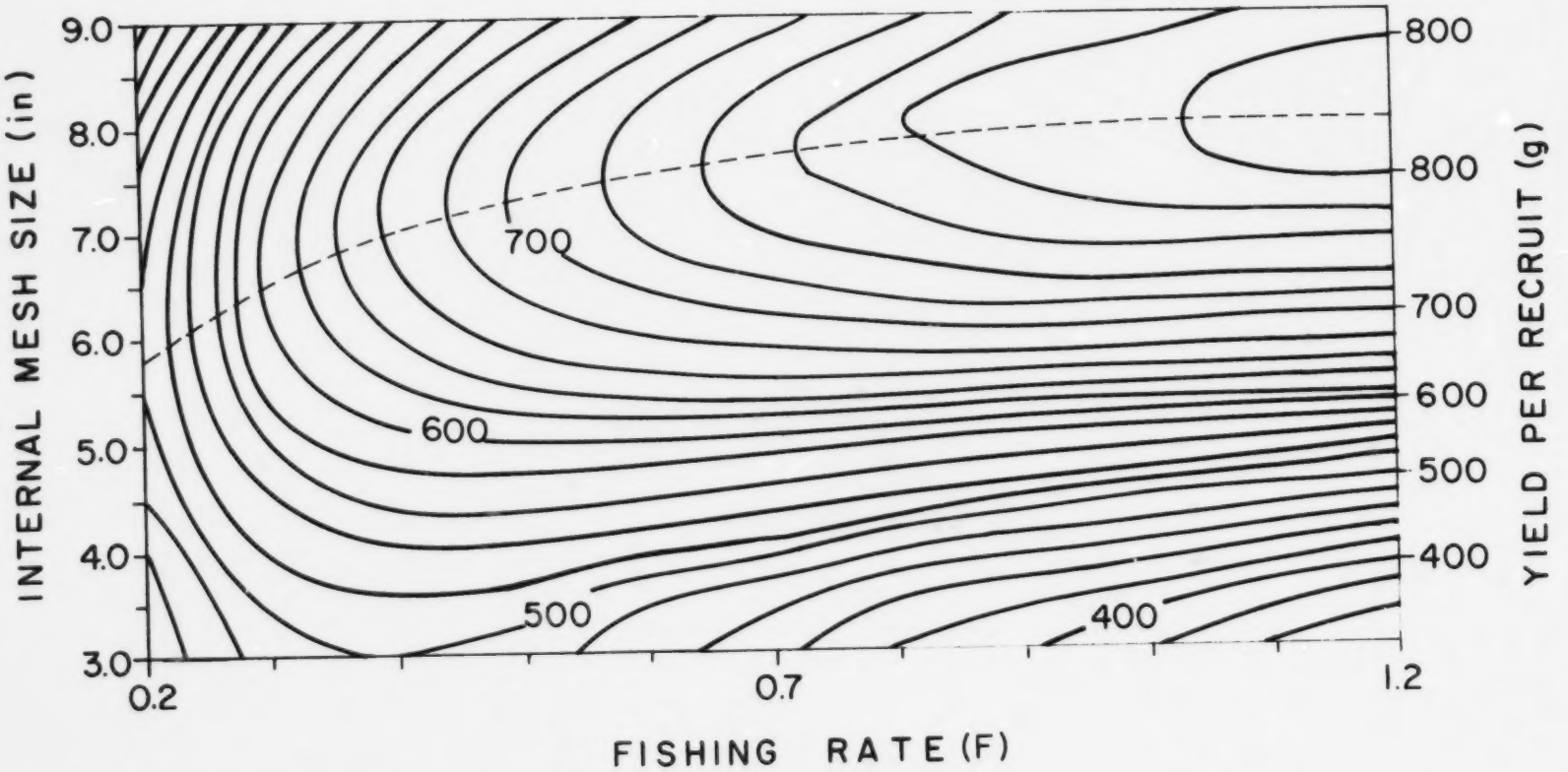

Fig. 10. Pacific cod yield (g) per age-1.0 recruit from Area 4B at: M=0.4; MCS=41 cm; and F=0.2-1.2.

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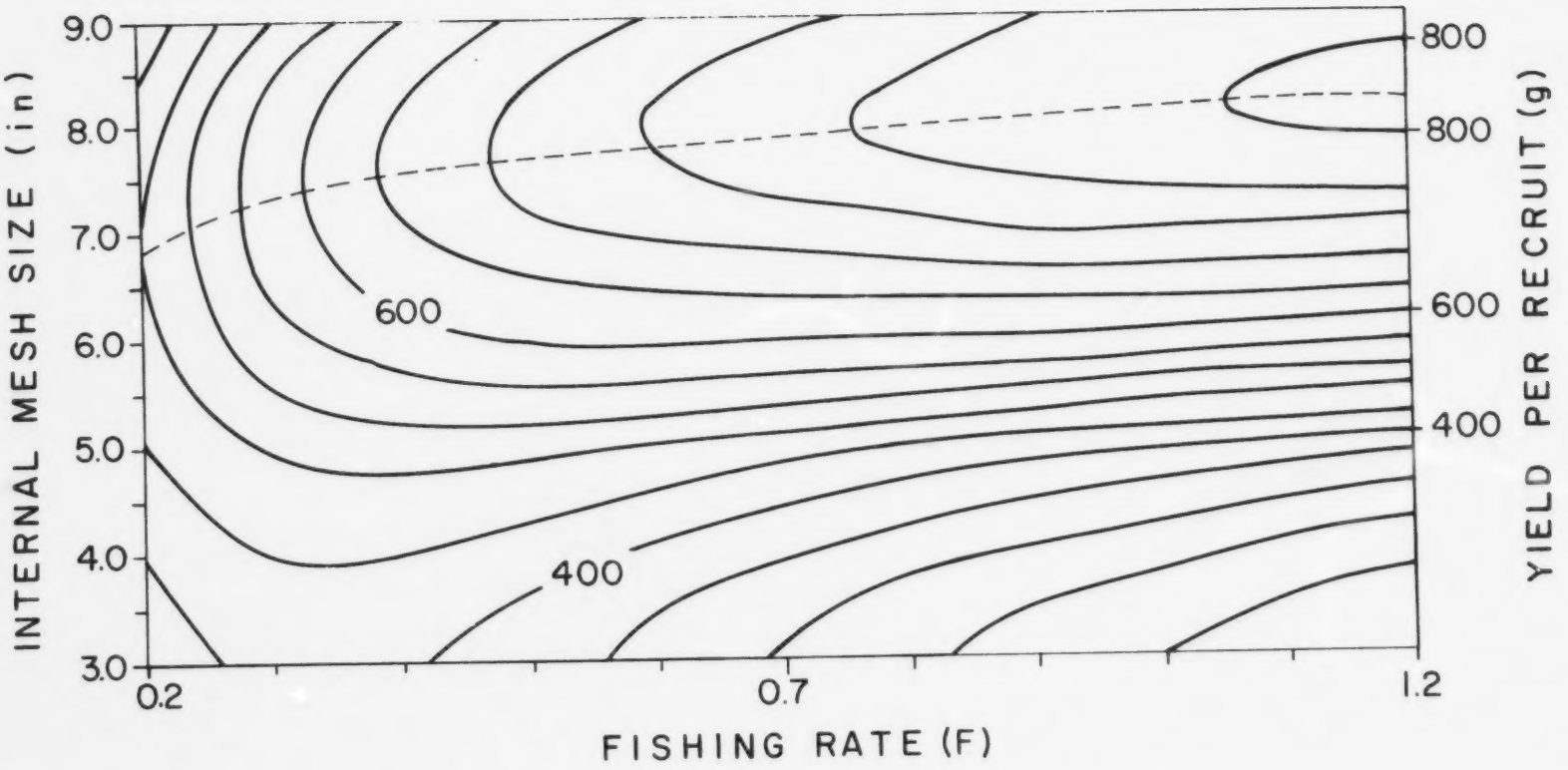

Fig. 11. Pacific cod yield (g) per age-1.0 recruit from Area 4B at: M=0.4; MCS=46 cm; and F=0.2-1.2.

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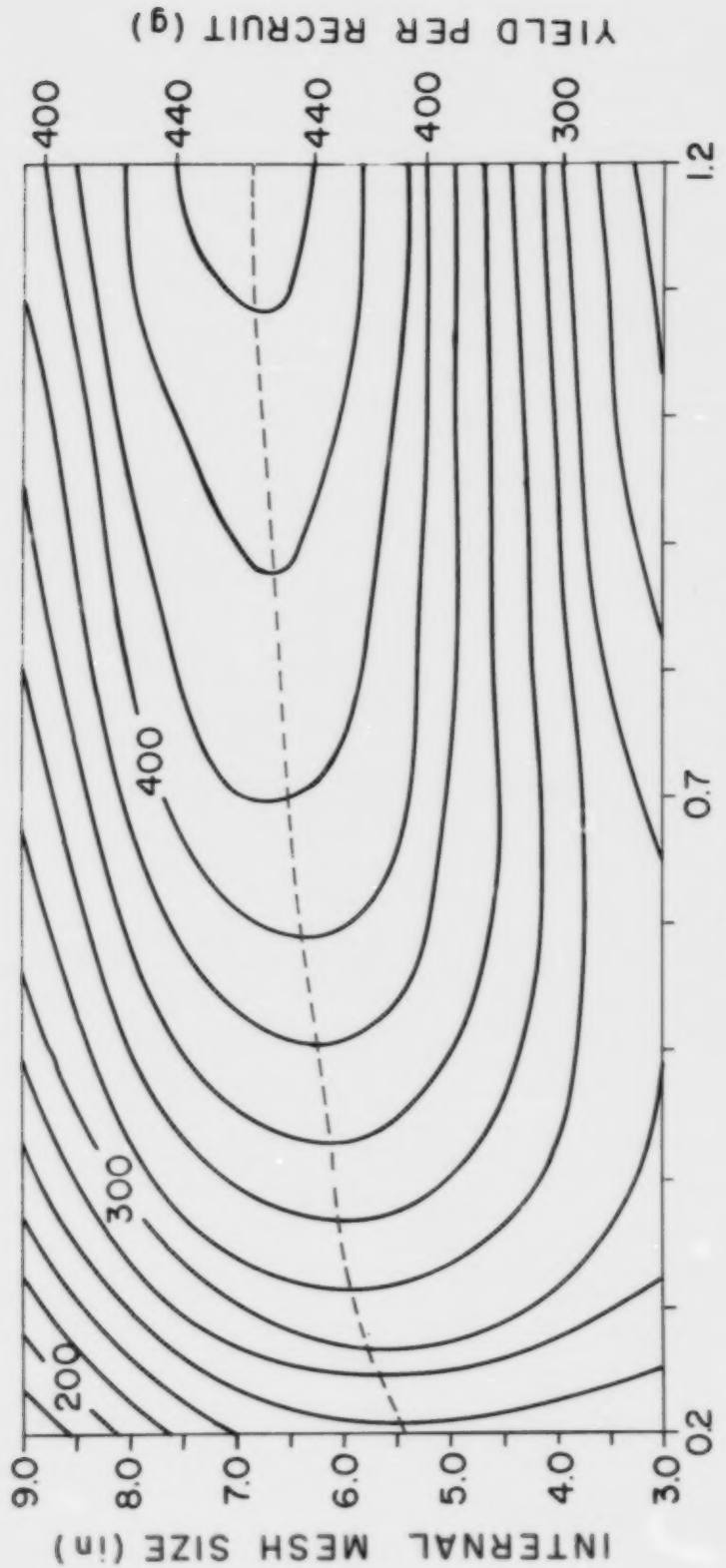

Fig. 12. Pacific cod yield (g) per age-1.0 recruit from Area 4B at: M=0.6; MCS=41 cm; and F=0.2-1.2.

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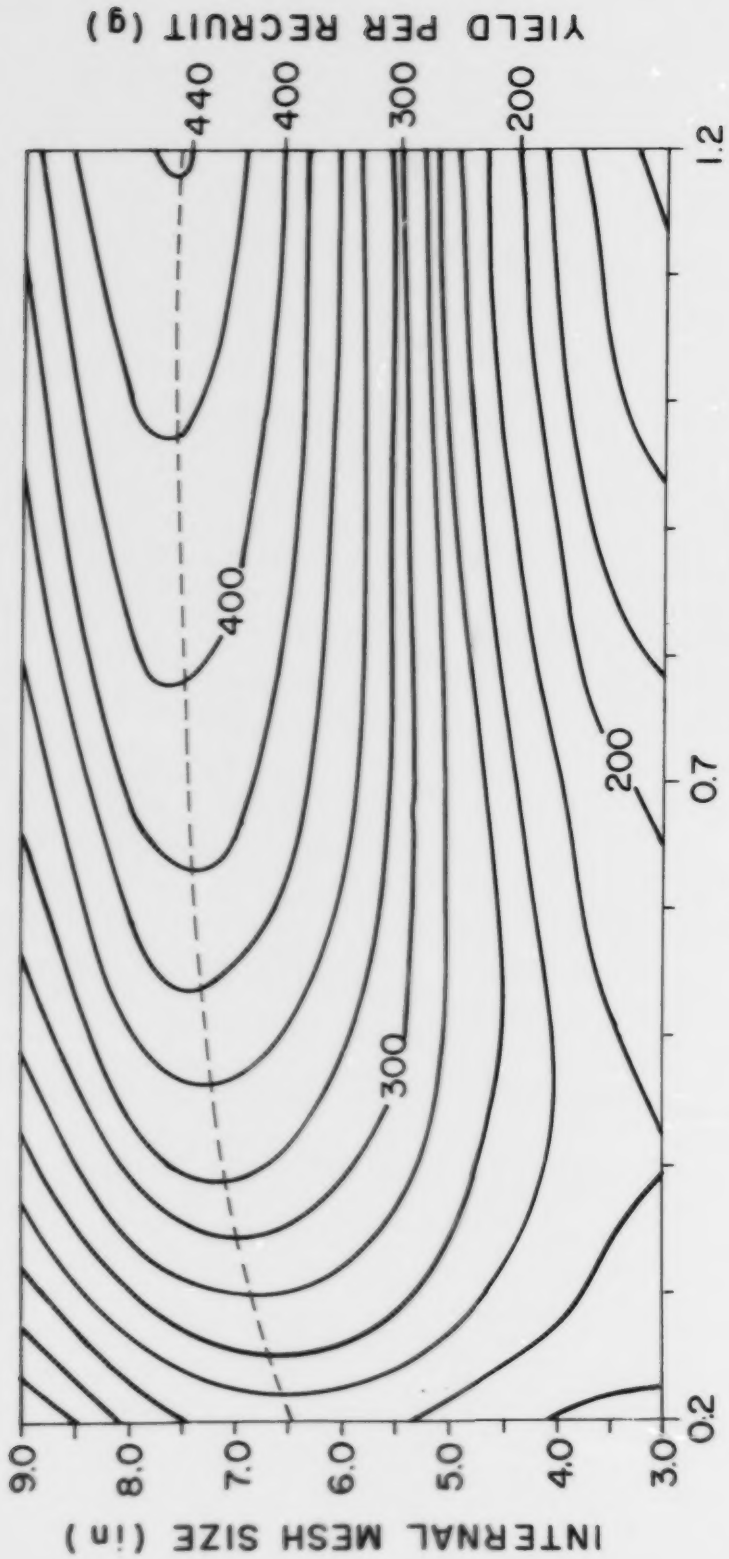

Fig. 13. Pacific cod yield (g) per age-1.0 recruit from Area 4B at: M=0.6; MCS=46 cm; and F=0.2-1.2.

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Table 1. Numbers of vessels involved in total (T) and interviewed (I) landings of Pacific cod from selected MSAs in Area 4B, by horsepower class and five-year period, 1955-84.

HP class	1955-59 T	1955-59 I	1960-64 T	1960-64 I	1965-69 T	1965-69 I	1970-74 T	1970-74 I	1975-79 T	1975-79 I	1980-84 T	1980-84 I
					MSA 14							
1	16	16	7	7	1	1	-	-	-	-	1	-
2	15	15	9	9	9	9	6	6	5	5	5	3
3	3	3	3	3	4	4	7	7	5	5	2	1
4	1	1	1	1	1	1	1	1	4	4	4	3
					MSA 17							
1	17	17	10	9	3	3	2	2	1	1	-	-
2	14	14	21	20	12	11	10	9	6	6	5	2
3	2	2	3	3	5	5	8	8	10	9	6	3
4	1	1	-	-	1	1	1	1	7	7	5	3
5	-	-	-	-	-	-	0	0	1	1	-	-
6	-	-	-	-	-	-	0	0	1	1	-	-
7	-	-	-	-	-	-	1	1	-	-	-	-
					MSA 18							
1	25	25	9	9	2	2	2	2	1	1	1	-
2	24	23	18	18	12	11	5	5	10	10	10	5
3	2	2	3	2	4	3	7	7	9	9	13	7
4	2	2	1	1	-	-	2	2	12	11	8	5
5	-	-	-	-	-	-	0	0	1	1	0	0
6	-	-	-	-	-	-	1	1	0	0	1	1
7	-	-	-	-	-	-	-	-	0	0	1	1
8	-	-	-	-	-	-	-	-	1	1	-	-
					MSA 19							
1	2	2	2	2	-	-	-	-	-	-	-	-
2	3	3	4	4	5	5	1	1	7	7	9	4
3	1	1	3	3	4	4	4	4	9	9	12	10
4	1	1	-	-	2	2	1	1	11	11	10	10
5	-	-	-	-	0	0	1	1	3	3	1	1
6	-	-	-	-	1	1	0	0	3	3	2	2
7	-	-	-	-	-	-	0	0	2	2	2	1
8	-	-	-	-	-	-	1	1	2	1	3	2

Table 1 (cont'd)

HP class	1955-59 T	1955-59 I	1960-64 T	1960-64 I	1965-69 T	1965-69 I	1970-74 T	1970-74 I	1975-79 T	1975-79 I	1980-84 T	1980-84 I
					MSA 20							
1	7	7	3	3	-	-	-	-	-	-	-	-
2	10	10	12	12	7	7	3	3	2	1	4	2
3	3	3	6	6	4	4	3	3	6	5	9	7
4	1	1	1	1	1	1	2	2	8	8	8	8
5	-	-	-	-	0	0	-	-	2	2	1	1
6	-	-	-	-	1	1	-	-	1	1	2	2
7	-	-	-	-	-	-	-	-	0	0	2	2
8	-	-	-	-	-	-	-	-	1	1	1	1
9	-	-	-	-	-	-	-	-	-	-	2	2
10	-	-	-	-	-	-	-	-	-	-	1	1

Table 2. Percent selection at various lengths relative to the length at 50% selection.

Length relative to length at 50% selection (cm)	% selection
-13 or less	0
-12	2
-11	4
-10	7
- 9	10
- 8	13
- 7	17
- 6	21
- 5	25
- 4	30
- 3	35
- 2	40
- 1	45
0	50
+ 1	55
+ 2	60
+ 3	65
+ 4	70
+ 5	75
+ 6	79
+ 7	83
+ 8	87
+ 9	90
+10	93
+11	96
+12	98
+13 or more	100

Table 3. Calculation of length at 50% selection for Pacific cod, by mesh size.

Mesh size[a] (in)	80% mesh perimeter (in)	Size at 50% selection		Calculated age at 50% selection[c] (y)
		girth (cm)	length[b] (cm)	
3.0	4.8	12.2	24.4	0.9
3.5	5.6	14.2	27.6	1.0
4.0	6.4	16.3	30.9	1.2
4.5	7.2	18.3	34.0	1.3
5.0	8.0	20.3	37.2	1.5
5.5	8.8	22.4	40.5	1.7
6.0	9.6	24.4	43.6	1.8
6.5	10.4	26.4	46.8	2.0
7.0	11.2	28.4	50.0	2.3
7.5	12.0	30.5	53.3	2.5
8.0	12.8	32.5	56.4	2.8
8.5	13.6	34.5	59.6	3.1
9.0	14.4	36.6	62.9	3.4

[a]Measured between the knots = 1/2 perimeter of opening.

[b]Length = 5.1647 + 1.5772 x girth, (R^2 = 0.99+).

[c]L_∞ = 87.5; K = 0.387; t_0 = -0.01.

Table 4. Mean of calculated monthly mean lengths and number of months included for each age and MSA in Area 4B, January-March, 1954-83.

Location		Age						
		2	3	4	5	6	7	8
MSA 14	Mean	48.3	58.6	66.1	71.9	76.4	80.3	83.4
	(N)	(43)	(44)	(44)	(41)	(36)	(20)	(9)
Nanoose (17-N)	Mean	48.7	58.8	66.2	72.2	76.6	80.2	82.2
	(N)	(45)	(48)	(48)	(47)	(43)	(19)	(8)
17-S	Mean	47.1	58.7	66.1	71.7	76.5	80.0	82.7
	(N)	(16)	(16)	(15)	(14)	(11)	(4)	(2)
MSA 18	Mean	48.3	58.6	65.6	71.4	75.8	79.6	82.4
	(N)	(50)	(51)	(50)	(49)	(37)	(26)	(17)
MSA 19	Mean	45.7	57.0	64.8	71.5	76.9	80.8	84.0
	(N)	(6)	(6)	(6)	(6)	(5)	(1)	(2)
Pooled mean		47.6	58.3	65.8	71.7	76.4	80.2	82.9

Table 5. Standardized landing statistics for Pacific cod from MSA 14, October-September, 1954-55 through 1984-85.

	Total		Interviewed				
	Oct-Sep		Oct-Mar	Oct-Dec		Jan-Mar	
Year	Effort (h)	Land. (t)	LPUE (kg/h)	Land. (t)	Effort (h)	Land. (t)	Effort (h)
1954-55	947	252	266	43	147	124	481
1955-56	707	133	188	10	90	76	368
1956-57	701	141	201	6	38	73	356
1957-58	623	99	159	29	156	20	153
1958-59	594	136	229	6	46	69	282
1959-60	598	131	219	17	59	91	434
1960-61	338	79	234	4	11	21	96
1961-62	288	55	191	10	48	25	135
1962-63	220	48	218	13	56	18	86
1963-64	895	111	124	37	299	57	461
1964-65	224	35	156	3	18	17	110
1965-66	209	19	91	1	12	2	21
1966-67	305	29	95	2	31	10	95
1967-68	263	20	76	4	39	4	66
1968-69	218	17	78	-	5	5	59
1969-70	233	30	129	13	73	7	82
1970-71	471	80	170	46	230	20	158
1971-72	409	65	159	22	176	18	75
1972-73	691	152	220	52	239	25	111
1973-74	(70)[a]	58	(825)	-	-	33	40
1974-75	241	75	311	20	70	35	107
1975-76	274	83	303	22	77	44	141
1976-77	220	98	445	30	58	23	61
1977-78	388	130	335	14	69	48	116
1978-79	112	48	429	2	20	25	43
1979-80	319	105	329	41	111	6	32
1980-81	233	91	390	41	67	28	110
1981-82	332	95	286	40	139	36	127
1982-83	225	41	182	1	12	11	54
1983-84	233	30	129	1	11	3	20
1984-85	(958)	69	(72)	0.07	1	0.36	5

[a]Numbers in parentheses not acceptable.

Table 6. Standardized landing statistics for Pacific cod from Nanoose (MSA 17-N) during January-March, 1954-84. (See Appendix table 1 for derivation of landings.)

Year	Total		Interviewed		
	Effort (h)	Land. (t)	LPUE (kg/h)	Land. (t)	Effort (h)
1954	309	108	349	102	292
1955	149	29	194	25	129
1956	274	87	318	76	239
1957	209	67	320	56	175
1958	538	197	366	165	451
1959	294	193	656	158	241
1960	668	181	271	129	476
1961	457	85	186	77	415
1962	260	63	242	43	178
1963	179	57	318	49	154
1964	419	85	203	62	306
1965	155	30	193	28	145
1966	UNK[a]	T[b]	(133)[c]	T	3
1967	198	132	667	126	189
1968	442	91	206	89	431
1969	158	18	114	17	149
1970	193	64	331	41	124
1971	525	303	577	286	496
1972	472	250	530	249	470
1973	299	121	405	34	84
1974	339	119	351	99	282
1975	111	32	287	25	87
1976	UNK	7	(333)	5	15
1977	UNK	1	(400)	T	1
1978	UNK	15	(667)	6	9
1979	95	36	378	14	37
1980	UNK	17	UNK	T	T
1981	UNK	10	UNK	-	-
1982	UNK	19	UNK	T	T
1983	UNK	7	UNK	-	-
1984	UNK	19	UNK	-	-

[a]UNK = unknown - could not be calculated.

[b]T=trace=<0.5 t.

[c]Numbers in parentheses not acceptable.

Table 7. Standardized landing statistics for Pacific cod from the Gulf Islands (MSA 17-S & 18) during October - September 1954-55 through 1984-85. (See Appendix table 2 for derivation of landings.)

	Total (17-S & 18)		Interviewed (18)				
	October-September		Oct-Mar	Oct-Dec		Jan-Mar	
Year	Effort (h)	Land. (t)	LPUE (kg/h)	Land. (t)	Effort (h)	Land. (t)	Effort (h)
1954-55	3215	627	195	101	440	269	1455
1955-56	2389	313	131	77	512	57	509
1956-57	1372	236	172	16	138	45	216
1957-58	1364	206	151	23	186	71	437
1958-59	1749	369	211	15	140	208	917
1959-60	2008	241	120	10	129	71	544
1960-61	1197	170	142	32	151	23	235
1961-62	1740	167	96	3	40	28	284
1962-63	3000	420	140	1	25	13	75
1963-64	2349	397	169	6	71	46	236
1964-65	1503	227	151	1	12	10	61
1965-66	913	94	103	1	41	23	193
1966-67	901	173	192	17	89	15	78
1967-68	1307	132	101	6	78	6	41
1968-69	1415	167	118	5	44	13	108
1969-70	1279	220	172	6	62	69	373
1970-71	1920	215	112	6	59	48	423
1971-72	960	214	223	29	142	21	82
1972-73	1034	210	203	10	31	37	200
1973-74	1297	271	209	-	-	24	115
1974-75	1284	262	204	9	71	42	179
1975-76	2508	499	199	24	158	97	451
1976-77	2045	450	220	T[a]	6	113	509
1977-78	2608	493	189	21	120	82	424
1978-79	894	295	330	7	34	52	145
1979-80	UNK[b]	333	(100)[c]	5	54	17	167
1980-81	UNK	330	(214)	-	6	9	36
1981-82	UNK	161	(122)	3	16	2	25
1982-83	UNK	127	(133)	-	-	T	3
1983-84	UNK	93	(480)	2	4	T	1
1984-85	UNK	(≤20)	UNK	-	-	-	-

[a]T=trace=<0.5t.

[b]UNK = unknown - could not be calculated.

[c]Numbers in parentheses not acceptable.

Table 8. Standardized landing statistics for Pacific cod from MSA 19, October - September, 1954-55 through 1984-85.

	Total		Interviewed				
	Oct-Sep		Oct-Mar	Oct-Dec		Jan-Mar	
Year	Effort (h)	Land. (t)	LPUE (kg/h)	Land. (t)	Effort (h)	Land. (t)	Effort (h)
1954-55	UNK[a]	20	UNK	-	-	-	-
1955-56	UNK	10	UNK	-	-	-	-
1956-57	(16)[b]	8	(500)	1	2	-	-
1957-58	UNK	40	UNK	-	-	-	-
1958-59	UNK	95	UNK	-	-	-	-
1959-60	333	147	441	30	68	-	-
1960-61	576	99	172	31	180	-	-
1961-62	UNK	50	UNK	T[c]	8	-	-
1962-63	247	37	150	2	15	T	1
1963-64	UNK	74	UNK	-	-	-	-
1964-65	293	81	276	32	116	-	-
1965-66	1008	119	118	55	466	-	-
1966-67	102	23	225	9	40	-	-
1967-68	(144)	48	(333)	1	3	-	-
1968-69	155	23	148	9	61	-	-
1969-70	336	79	235	20	85	-	-
1970-71	250	47	188	25	133	-	-
1971-72	88	13	148	3	22	1	5
1972-73	57	12	211	4	19	-	-
1973-74	UNK	52	UNK	-	-	-	-
1974-75	1137	258	227	22	97	-	-
1975-76	1358	463	341	141	413	-	-
1976-77	570	244	428	71	166	-	-
1977-78	1939	696	359	292	787	42	143
1978-79	1859	554	298	168	550	46	168
1979-80	3865	804	208	119	564	24	123
1980-81	2728	851	312	224	854	105	200
1981-82	3375	928	275	377	1387	156	553
1982-83	2097	543	259	41	168	32	114
1983-84	1538	483	314	53	168	T	2
1984-85	526	244	464	52	112	-	-

[a]UNK = unknown - could not be calculated.

[b]Numbers in parentheses not acceptable.

[c]T = trace = <0.5 t.

Table 9. Standardized landing statistics for Pacific cod from MSA 20, October - September, 1954-55 through 1984-85.

	Total		Interviewed				
	Oct-Sep		Oct-Mar	Oct-Dec		Jan-Mar	
Year	Effort (h)	Land. (t)	LPUE (kg/h)	Land. (t)	Effort (h)	Land. (t)	Effort (h)
1954-55	84	41	489	4	8	T[a]	1
1955-56	97	22	227	3	14	T	1
1956-57	220	13	59	3	57	T	1
1957-58	530	41	117	T	11	-	-
1958-59	532	62	156	7	60	-	-
1959-60	(165)[b]	83	(182)	1	8	T	1
1960-61	765	30	102	4	22	-	-
1961-62	496	78	139	5	49	-	-
1962-63	524	69	105	14	101	-	-
1963-64	638	55	138	7	69	1	7
1964-65	520	88	152	8	66	8	50
1965-66	77	79	594	7	53	15	92
1966-67	239	46	243	21	30	T	6
1967-68	1750	58	48	3	12	T	2
1968-69	850	84	100	2	42	-	-
1969-70	UNK[c]	93	UNK	-	-	-	-
1970-71	850	85	100	4	40	-	-
1971-72	438	98	224	11	49	-	-
1972-73	(22)	11	(500)	1	2	-	-
1973-74	UNK	7	UNK	-	-	-	-
1974-75	UNK	84	UNK	-	-	-	-
1975-76	UNK	14	UNK	-	-	-	-
1976-77	UNK	54	UNK	-	-	-	-
1977-78	315	74	235	-	-	23	98
1978-79	660	229	347	3	13	71	200
1979-80	1120	243	217	14	58	155	722
1980-81	1223	203	166	4	24	79	477
1981-82	286	115	402	4	31	37	71
1982-83	1481	114	77	2	16	1	23
1983-84	493	101	205	T	1	15	74
1984-85	779	116	149	-	-	14	94

[a] T = trace = <0.5 t.

[b] Numbers in parentheses not acceptable.

[c] UNK = unknown - could not be calculated.

Table 10. Landings (t), standardized effort (h), and LPUE-at-age (nos./h) for Pacific cod from MSA 14, January-March, 1954-82.

Year	Land. (t)	Effort (h)	LPUE (nos./h) at age: 2	3	4	5	6	7	8	9
1954	216	690	6.9	32.3	21.0	10.9	3.5	1.6	0.1	0.1
1955	160	620	8.6	45.1	27.9	4.6	1.8	0.5	0.2	-
1956	87	420	5.3	39.4	16.2	6.3	0.1	0.3	-	-
1957	40	439	16.7	38.2	19.4	7.2	1.3	0.2	0.5	-
1958	54	412	11.7	5.0	2.6	0.4	0.3	-	-	-
1959	88	359	20.4	30.8	2.4	1.5	0.3	-	-	0.1
1960	98	467	4.0	24.3	16.1	1.0	1.4	0.1	0.2	-
1961	37	169	22.8	28.4	14.5	6.3	1.5	0.8	-	-
1962	38	205	1.7	14.0	18.7	4.2	1.3	0.1	0.1	-
1963	26	124	23.4	14.8	8.1	0.5	1.4	-	-	0.1
1964	63	508	6.2	18.2	5.2	1.3	0.6	0.2	-	-
(1965)[a]	26	168	(7.6)[b]	(14.2)	(4.5)	(2.8)	(2.1)	(-)	(-)	(-)
1966	13	137	24.4	9.4	5.5	1.8	0.4	-	-	-
1967	21	200	22.7	16.8	8.8	0.5	0.3	-	-	-
1968	9	148	5.6	3.9	1.0	-	-	-	-	-
(1969)[a]	9	106	(7.2)	(5.7)	(0.5)	(0.2)	(-)	(-)	(-)	(-)
1970	11	129	9.4	8.9	1.2	1.3	-	-	-	-
1971	25	197	21.0	6.0	7.6	1.9	0.1	-	-	-
1972	22	92	18.5	38.9	15.0	-	-	-	-	-
1973	36	160	3.4	13.9	22.3	4.8	6.7	1.5	0.4	-
(1974)	34	(70)	----------	----------	----------	No samples	----------	----------	----------	----------
1975	39	119	47.1	32.7	21.3	8.2	0.7	1.1	-	-
1976	51	163	15.7	26.4	31.7	14.7	5.3	1.8	1.0	-
(1977)	31	82	(12.4)	(17.9)	(10.2)	(2.9)	(2.0)	(0.4)	(-)	(-)
1978	71	171	17.2	70.2	15.8	9.1	1.3	0.8	-	-
1979	42	72	87.2	84.8	67.6	13.8	2.6	0.9	-	-
(1980)[a]	32	170	(18.9)	(2.5)	(5.4)	(-)	(0.2)	(-)	(-)	(-)
(1981)	45	233	----------	----------	----------	No samples	----------	----------	----------	----------
1982	39	138	24.8	2.3	1.4	0.2	0.1	-	-	-
Mean		246	18.5	26.3	15.3	4.4	1.3	0.4	0.1	T[c]

[a]Inadequate sample: N = 84 (1965); 63 (1969); 120 (1980).

[b]Parenthetical values excluded in computing the mean.

[c]T = trace = <0.5 t.

Table 11. LPUE-at-age (nos./h) for selected year-classes, and estimates of Z, M, q, and F for Pacific cod from MSA 14, January-March 1954-82.

Year class	LPUE (nos./h) at age: 3	4	5	6	Mean annual effort (h) (Oct-Sep)	$\hat{Z}$	F[a]
1952	45.1	16.2	7.2	0.3	745	1.59	1.02
1953	39.4	19.4	0.4	0.3	656	1.85	0.90
1954	38.2	2.6	1.5	1.4	629	1.05	0.86
(1955)[b]	(5.0)	(2.4)	(1.0)	(1.5)	-	(0.45)	-
1956	30.8	16.1	6.3	1.3	455	1.04	0.62
1957	24.3	14.5	4.2	1.4	361	0.98	0.50
1958	28.4	18.7	0.5	0.6	435	1.52	0.60
(1967)[b]	(8.9)	(7.6)	(0.0)	(6.7)	-	(0.09)	-
Mean	34.4	14.6	3.4	0.9	547	1.24	0.75

Note: For Z on effort:
$a = M = 0.59$
$b = q = 1.373 \times 10^{-3}$
$R^2 = 0.32$

[a] $F = q\bar{E}$

[b] Not acceptable.

Table 12. Estimates of Z, by method, for principal stocks of Pacific cod in Area 4B.

		Stock				
		MSA 14[a] (Jan-Mar)	Nanoose[a] (Jan-Mar)	Gulf Is.[a] (Jan-Mar)	MSA 19[b] (Oct-Dec)	MSA 20[a] (Jan-Mar)
1. Among years						
a. Mean A-F	Z	1.03	1.35	1.11	1.26	-
(regression)	(R^2)	(.97)	(.99+)	(.99+)	(.99+)	-
2. Among year-classes						
a. Mean Z	Z	1.34	1.50	1.28	1.63	-
	(C.V., %)	(27)	(21)	(32)	(28)	-
b. Mean A-F	Z	1.24	1.48	1.41	1.49	-
(regression)	(R^2)	(.99)	(.99+)	(.99+)	(.98)	-
3. Among age-classes (regression)						
a. Jan-Mar 1966	Z	-	-	-	-	1.16
	(R^2)	-	-	-	-	(.91)
b. Jan-Mar 1982	Z	-	-	-	-	1.32
	(R^2)	-	-	-	-	(.93)

[a]Ages 3-6.

[b]Ages 2-5.

Table 13. Landings (t), standardized effort (h), and LPUE-at-age (nos./h) for Pacific cod from Nanoose (MSA 17-N), January-March, 1954-79.

Year	Land. (t)	Effort (h)	LPUE (nos./h) at age: 2	3	4	5	6	7	8	9	10
1954	108	309	19.9	94.1	26.0	2.8	2.5	-	-	-	-
1955	29	149	2.7	34.8	11.8	7.0	1.2	-	0.2	-	-
1956	87	274	18.6	79.7	32.2	5.6	0.6	0.5	0.2	-	-
1957	67	209	3.9	96.8	15.1	6.4	1.1	-	-	-	-
1958	197	538	20.0	83.3	26.3	3.6	1.7	-	-	-	-
1959	193	294	4.4	255.5	9.7	7.4	1.0	-	-	-	-
1960	181	668	13.3	46.4	28.6	4.9	0.1	0.1	-	-	-
1961	85	457	15.2	47.1	11.3	1.2	0.6	-	-	-	-
1962	62	256	27.7	55.5	9.0	0.6	1.1	-	-	-	-
1963	57	179	40.3	84.7	12.9	1.5	1.9	-	-	-	-
1964	85	419	16.6	37.8	13.0	5.3	1.3	0.2	0.2	-	0.1
1965	30	155	8.6	55.7	12.0	2.7	1.1	0.3	-	-	-
1966	T[a]	UNK[b]	No samples								
1967	132	198	5.9	252.8	19.0	1.9	0.3	-	-	-	-
1968	91	442	2.5	70.6	16.8	2.6	0.3	-	-	-	-
1969	18	158	15.7	21.9	9.0	1.5	0.6	-	-	-	-
1970	64	193	46.8	29.0	24.3	5.1	2.4	0.9	0.2	-	-
1971	303	525	58.9	109.5	70.8	9.3	1.8	-	-	0.2	-
1972	250	472	7.7	138.4	57.8	13.5	5.6	0.4	-	-	-
1973	121	299	29.2	70.5	38.5	1.9	7.8	0.4	0.7	0.1	0.1
1974	119	339	31.6	28.1	36.6	11.8	2.3	1.3	0.5	-	-
1975	32	111	24.0	42.3	12.1	3.8	0.6	0.5	-	-	-
1976	7	267	No samples								
1977	T	UNK	No samples								
1978	15	22	15.0	182.4	21.8	11.4	1.1	-	-	-	-
1979	36	95	28.7	87.2	16.6	6.0	0.8	1.0	0.6	-	-
Mean			19.9	86.3	23.1	5.1	1.6	0.2	0.1	T	T

[a]T=trace = <0.5 t landed, or <0.05 fish/h.

[b]UNK = unknown.

Table 14. LPUE-at-age (nos./h) for selected year-classes, and estimates of Z for Pacific cod from Nanoose (MSA 17-N), January-March, 1954-69.

Year class	LPUE (nos./h) at age: 3	4	5	6	$\hat{Z}$
1951	94.1	11.8	5.6	1.1	1.41
1952	34.8	32.2	6.4	1.7	1.07
1953	79.7	15.1	3.6	1.0	1.46
1954	96.8	26.3	7.4	0.1	2.19
1955	83.3	9.7	4.9	0.6	1.55
1956	255.5	28.6	1.2	1.1	1.95
1957	46.4	11.3	0.6	1.9	1.25
1958	47.1	9.0	1.5	1.3	1.26
1959	55.5	12.9	5.3	1.1	1.27
1964	252.8	16.8	1.5	2.4	1.64
1965	70.6	9.0	5.1	1.8	1.16
(1966)[a]	(21.9)	(24.3)	(9.3)	(5.6)	(0.51)
(1967)[a]	(29.0)	(70.8)	(13.5)	(7.8)	(0.56)
1968	109.5	57.8	1.9	2.3	1.50
1969	138.4	38.5	11.8	0.6	1.75
Mean	104.9	21.5	4.4	1.3	1.50

[a]Not acceptable.

Table 15. Landings (t), standardized effort (h), and LPUE-at-age (nos./h) for Pacific cod from the Gulf Islands (17-S & 18) January-March, 1954-79. (Age frequencies from MSA 18 only.)

Year	Land. (t)	Effort (h)	LPUE (nos./h) at age: 2	3	4	5	6	7	8	9	10
1954	338	1330	41.6	19.9	3.7	3.7	1.0	0.3	0.5	-	-
1955	352	1903	7.0	34.8	17.9	5.5	2.2	0.6	0.2	0.1	-
1956	111	991	33.6	13.7	6.1	2.3	0.6	0.4	0.3	-	-
1957	138	663	43.4	31.6	5.5	1.8	-	0.4	-	-	-
1958	97	599	10.5	6.2	2.0	0.4	0.2	-	-	-	-
1959	292	1286	37.2	57.3	8.9	1.5	0.6	0.3	-	-	-
1960	135	1031	24.7	17.5	8.7	1.3	0.5	0.1	0.1	-	-
1961	93	949	1.4	11.9	2.4	4.2	4.5	1.3	1.1	0.2	0.4
1962	122	1232	13.2	19.6	4.4	2.4	0.2	0.1	-	-	-
(1963)			No samples								
1964	207	1062	40.6	19.3	9.0	1.8	0.3	0.1	-	-	-
1965	135	823	8.5	7.6	2.8	0.5	0.3	-	-	-	-
1966	51	429	33.1	3.7	2.3	0.3	-	-	-	-	-
1967	87	453	49.2	3.0	1.4	-	-	-	-	-	-
(1968)[a]	30	205	(27.3)	(3.1)	(1.0)	(0.7)	(-)	-	-	-	-
1969	53	442	18.5	7.0	7.3	1.3	0.1	0.2	-	-	-
1970	118	638	78.4	9.2	6.9	2.0	0.6	-	0.1	0.1	-
1971	101	894	45.4	20.8	5.9	2.5	0.4	0.2	0.1	0.1	-
(1972)[a]	67	262	(36.5)	(15.1)	(3.5)	(0.6)	(-)	(-)	(0.3)	(-)	(-)
(1973)[a]	121	654	(10.4)	(3.0)	(2.2)	(0.1)	(0.5)	(-)	(-)	(-)	(-)
1974	163	780	28.9	9.2	2.9	0.7	0.6	-	-	-	-
1975	121	515	70.8	0.3	-	0.2	0.2	-	-	-	-
1976	189	879	12.0	32.8	2.2	0.5	0.8	-	-	-	0.1
1977	202	910	75.2	22.3	7.0	1.9	0.7	-	-	-	-
1978	289	1497	29.9	25.6	6.6	3.3	1.2	0.2	0.3	0.1	-
1979	192	535	53.2	31.5	18.1	8.9	0.5	-	-	0.4	-
Mean			34.4	18.4	6.0	2.1	0.7	0.2	0.1	T[b]	T

[a]Inadequate sample: N = 137 (1968); 169 (1972); 160 (1973).

[b]T = trace = <0.05.

Table 16. LPUE-at-age (nos./h) for selected year-classes, estimates of Z, M, and q for Pacific cod from the Gulf Islands (17-S & 18) January-March, 1954-79.

Year class	LPUE (nos./h) at age: 3	4	5	6	Mean annual effort (h) (Oct-Sept)	Z
1952	34.8	6.1	1.8	0.2	1849	1.67
1953	13.7	5.5	0.4	0.6	1488	1.20
1954	31.6	2.0	1.5	0.5	1359	1.27
(1955)[a]	(6.2)	(8.9)	(1.3)	(4.5)	-	(0.29)
1956	57.3	8.7	4.2	0.2	1469	1.77
1961	19.3	2.8	0.3	0.0	1251	2.08
(1971)[a]	(9.2)	(0.0)	(0.5)	(0.7)	-	(0.94)
(1972)[a]	(0.3)	(2.2)	(1.9)	(1.2)	-	(-0.40)
1973	32.8	7.0	3.3	0.5	1732	1.33
Mean	29.9	7.1	2.0	0.3		1.49

Note: For Z on effort:
$a = M = 2.18$
$b = q = 4.109 \times 10^{-4}$
$R^2 = 0.072$

[a]Not acceptable.

Table 17. Landings (t), standardized effort (h), and LPUE-at-age (nos./h) for Pacific cod landed from MSA 19 during October-December 1959-60, 1964-65, 1970, and 1975-84.

Year	Land. (t)	Effort (h)	LPUE (nos./h) at age: 1	2	3	4	5	6	7	8	9
1959	132	299	-	4.5	106.3	10.2	-	-	-	-	-
1960	77	448	-	15.1	8.2	5.6	0.5	-	-	-	-
1964	66	239	4.0	69.6	7.6	1.4	0.5	-	-	-	-
1965	107	907	0.1	36.2	3.3	0.6	0.3	-	-	-	-
1970	34	181	9.4	64.4	13.0	5.4	0.9	-	-	-	-
1975	253	742	-	42.9	5.5	7.9	5.9	0.8	0.6	-	-
1976	138	322	2.1	61.8	43.1	12.5	1.4	2.6	-	0.2	-
1977	386	1040	8.1	147.2	16.9	14.1	2.4	1.2	-	0.2	-
1978	336	1102	32.9	47.9	20.1	2.3	0.3	0.3	0.2	-	-
1979	325	1540	28.4	39.1	15.3	5.8	1.1	1.1	0.6	0.3	0.1
(1980)[a]	394	1438	(11.9)	(24.1)	(0.2)	(4.0)	(0.6)	(-)	(-)	(-)	(-)
1981	500	1838	9.5	162.0	10.6	2.7	1.5	-	-	-	-
1982	189	775	105.3	14.1	35.3	3.0	0.3	0.4	0.4	-	-
1983	268	851	97.3	60.7	13.4	10.7	0.1	0.9	-	-	-
1984	149	321	148.2	22.4	6.6	2.0	-	-	-	-	-
1975-84 Mean			48.0	66.5	18.5	6.8	1.4	0.8	0.1	0.1	T[b]

[a]Inadequate sample N = 120.

[b]T = trace = <0.05 fish/h.

Table 18. Estimates of Z for selected year-classes of Pacific cod from MSA 19.

Year class	LPUE (nos./h) at age: 2	3	4	5	Z	R^2
1973	42.9	43.1	14.1	0.3	1.60	0.77
1974	61.8	16.9	2.3	1.1	1.41	0.97
1979	162.0	35.3	10.7	0	1.64	0.97
Mean	88.9	31.8	9.0	0.5	1.55	0.96

Note: $\bar{Z}$ (among year-classes) = 1.55 (C.V. = 8%).

Table 19. Stomach contents of Pacific cod landed from Nanoose, by date of landing, 1951-79.

Year	Date	Stomach contents
1951	Mar 8	Herring
	22	Herring, full of spawn
1954	Feb 3	Herring, large
	Mar 4	Herring
1963	Mar 28	Herring, large
1973	Feb 23	Herring
	Mar 2	Herring
	13	Herring
1974	Mar 15	Herring, "heavily"
	21	Herring, "heavily"
	21	Herring, "heavily"
1978	Mar 21	Herring
	21	Herring
	23	Herring; euphausiids; pile perch[a]
1979	Feb 27	Herring
	Mar 8	Herring

[a]Rhacochilus vacca

Table 20. Numbers of low-salinity "events" (<26.0°/..) at Entrance Island Lighthouse, by month and year, January-March 1957-84.

Year	Nos. of "events"					Landings (t)	Cumul. year-class LPUE (nos./h)
	Jan	Feb	Mar	Total	Feb-Mar		
1957	-	1	-	1	1	67	60.2
1958	6	6	8	20	14	197	58.9
1959	5	2	-	7	2	193	74.8
1960	1	7	-	8	7	181	
1961	9	10	8	27	18	85	
1962	8	4	4	16	8	63	
1963	12	8	2	22	10	57	
1964	1	1	-	2	1	85	273.5
1965	-	1	-	1	1	30	86.5
1966	1	2	-	3	2	T[a]	61.1
1967	7	7	5	19	12	132	121.1
1968	-	15	6	21	21	91	171.5
1969	-	1	-	1	1	18	189.3
1970	-	4	-	4	4	64	
1971	-	1	-	1	1	303	
1972	-	1	7	8	8	250	
1973	2	-	3	5	3	121	
1974	2	5	4	11	9	119	
1975	-	-	-	-	-	32	
1976	9	1	2	12	3	7	
1977	2	-	-	2	-	1	
1978	1	-	1	2	1	15	
1979	-	-	-	-	-	36	
1980	-	1	-	1	1	17	
1981	13	-	1	14	1	10	
1982	1	2	1	4	3	19	
1983	4	1	3	8	4	7	
1984	10	2	-	12	2	19	

[a] T = trace = <0.5 t.

Table 21. Pacific cod yield (g) per age-1.0 recruit from Area 4B at: M=0.4, MCS=41 and 46 cm; and F=0.2-1.2.

Mesh size	Fishing mortality (F)										
(in)	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2
Minimum commercial size = 41 cm											
3.0	447	491	500	490	467	442	416	402	380	355	342
3.5	450	508	516	507	479	465	437	424	409	388	369
4.0	460	523	540	535	521	509	482	472	458	438	422
4.5	480	542	566	566	556	551	535	521	505	497	486
5.0	492	562	586	599	596	589	582	574	569	562	550
5.5	503	584	622	640	653	647	653	647	638	641	635
6.0	503	596	638	674	683	690	692	703	695	693	689
6.5	499	600	659	681	705	721	729	741	739	735	735
7.0	496	600	661	701	722	742	748	772	774	772	774
7.5	477	594	662	704	730	754	772	783	793	805	804
8.0	470	582	651	695	726	749	779	791	794	813	817
8.5	434	554	625	675	707	736	757	780	790	800	805
9.0	410	514	599	647	680	713	731	759	767	780	794
Minimum commercial size = 46 cm											
3.0	387	409	404	382	347	314	284	265	240	214	201
3.5	390	425	418	393	355	334	298	279	260	238	216
4.0	400	439	439	419	390	368	334	316	297	272	251
4.5	421	461	467	451	428	409	384	363	339	324	306
5.0	438	487	495	490	474	457	438	420	407	395	376
5.5	460	524	546	552	554	535	532	517	500	497	485
6.0	470	548	579	601	603	600	594	598	586	577	567
6.5	475	568	615	631	648	657	660	667	659	651	649
7.0	481	578	635	672	687	703	704	725	723	719	718
7.5	470	584	650	689	713	735	750	759	769	778	777
8.0	467	579	647	690	721	744	773	785	787	806	810
8.5	434	554	625	675	707	736	757	780	790	800	805
9.0	410	514	599	647	680	713	731	759	767	780	794

Table 22. Pacific cod yield (g) per age-1.0 recruit from Area 4B at: M=0.6, MCS=41 and 46 cm; and F=0.2-1.2.

Mesh size	Fishing mortality (F)										
(in)	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2
Minimum commercial size = 41 cm											
3.0	242	275	297	298	302	293	281	272	262	254	246
3.5	243	279	304	310	309	308	297	286	279	275	269
4.0	246	292	320	328	329	334	323	322	313	310	303
4.5	249	301	330	349	356	360	352	354	350	346	346
5.0	254	309	344	361	370	377	384	382	381	384	379
5.5	257	315	350	374	393	407	408	415	416	425	424
6.0	250	311	349	375	402	415	427	433	439	448	452
6.5	245	306	346	378	401	417	429	441	449	461	466
7.0	237	300	344	370	399	419	430	441	451	459	469
7.5	225	283	332	362	383	407	420	430	441	455	464
8.0	204	267	312	343	365	389	402	413	424	442	444
8.5	181	237	280	312	335	352	370	386	394	408	422
9.0	161	211	251	282	309	324	341	353	364	380	386
Minimum commercial size = 46 cm											
3.0	196	212	221	213	207	193	177	164	151	144	133
3.5	196	216	224	222	210	204	187	172	161	154	146
4.0	199	228	239	238	226	223	204	200	185	180	169
4.5	206	239	250	260	255	248	233	226	217	208	204
5.0	212	252	271	278	276	274	271	262	255	250	241
5.5	224	268	291	305	315	319	314	313	309	313	306
6.0	223	274	303	322	339	348	351	352	353	356	357
6.5	227	281	314	338	357	368	375	384	387	395	398
7.0	225	283	323	347	372	388	396	405	414	419	425
7.5	220	276	322	351	370	391	403	412	422	435	442
8.0	204	264	309	339	361	385	397	409	419	437	438
8.5	181	237	280	312	335	352	370	386	394	408	422
9.0	161	211	251	282	309	324	341	353	364	380	386

Table 23. Catch-profitability indices (YPR/F) for YPR maxima of selected mesh sizes, at M=0.4 and 0.6, and MCS=41 and 46 cm. (Source: Tables 21 and 22.)

Minimum commercial size (cm)		Mesh size (in)					
		3.0	4.0	4.5	5.0	5.5	6.0
				M = 0.4			
41	YPR/F[a]	1250	1350	1415	1198	1088	781
	YPR	500	540	566	599	653	703
	F	0.4	0.4	0.4	0.5	0.6	0.9
46	YPR/F	1363	1463	1168	1238	923	1005
	YPR	409	439	467	495	554	603
	F	0.3	0.3	0.4	0.4	0.6	0.6
				M = 0.6			
41	YPR/F	503	477	514	480	386	377
	YPR	302	334	360	384	425	452
	F	0.6	0.7	0.7	0.8	1.1	1.2
46	YPR/F	553	598	520	556	456	298
	YPR	221	239	260	278	319	357
	F	0.4	0.4	0.5	0.5	0.7	1.2

[a]YPR = yield (g) per age-1.0 recruit; F = instantaneous fishing mortality rate.

Appendix table 1. Estimated total landings (t) of Pacific cod from Nanoose (17-N) during January-March 1954-84. (Source: Foucher and Giudici 1985, Tables 4 and 8.)

	Interviewed			Total		
Year	17-N	17-S	Total	17	17-N	17-S
1954	102	19	121	128	108	20
1955	26	3	29	32	29	3
1956	76	7	83	95	87	8
1957	59	9	68	77	67	10
1958	166	3	169	201	197	4
1959	158	3	161	197	193	4
1960	129	1	130	182	181	1
1961	78	1	79	86	85	1
1962	43	T	43	63	63	T
1963	50	33	83	94	57	37
1964	62	8	70	96	85	11
1965	28	1	29	31	30	1
1966	T[a]	7	7	8	T	8
1967	126	10	136	142	132	10
1968	89	10	99	101	91	10
1969	17	14	31	32	18	14
1970	41	10	51	80	64	16
1971	286	6	292	309	303	6
1972	249	20	269	270	250	20
1973	67	2	69	125	121	4
1974	101	4	105	124	119	5
1975	25	28	53	68	32	36
1976	5	22	27	36	7	29
1977	T	13	13	27	1	26
1978	6	12	18	46	15	31
1979	14	1	15	39	36	3
1980	T	T	T	19	17[a]	2
1981	T	T	T	11	10[a]	1
1982	T	T	T	21	19[a]	2
1983	-	-	-	8	7[a]	1
1984	-	T	T	21	19[a]	2
%	89	11	100			

[a]T = trace = <0.5 t.

[b](0.89) (Total for MSA 17).

Appendix table 2. Total landings (t), by quarter-year, of Pacific cod from the Gulf Islands (MSAs 17-S and 18), 1954-84.

	Oct-Dec			Jan-Mar			Apr-Jun			Jul-Sep			Oct-Sep
Year	17-S[a]	18[b]	Total	17-S[c]	18[b]	Total	17-S[a]	18[b]	Total	17-S[a]	18[b]	Total	Total
1954-55	21	177	198	3	352	355	9	55	64	2	8	10	627
1955-56	12	139	151	8	111	119	19	15	34	9	T[d]	9	313
1956-57	13	61	74	10	138	148	7	6	13	-	1	1	236
1957-58	16	64	80	4	97	101	13	10	23	1	1	2	206
1958-59	11	31	42	4	292	296	18	12	30	-	1	1	369
1959-60	36	35	71	1	135	136	23	11	34	T	T	T	241
1960-61	8	60	68	1	93	94	5	2	7	T	1	1	170
1961-62	5	32	37	T	122	122	1	6	7	-	1	1	167
1962-63	2	59	61	37	82	219	50	84	134	5	1	6	420
1963-64	22	112	134	11	207	218	20	24	44	-	1	1	397
1964-65	11	66	77	1	135	136	2	11	13	T	1	1	227
1965-66	6	25	31	8	51	59	3	-	3	-	1	1	94
1966-67	6	52	58	10	87	97	2	6	8	-	10	10	173
1967-68	20	47	67	10	30	40	6	16	22	-	3	3	132
1968-69	19	57	76	14	53	67	8	7	15	-	9	9	167
1969-70	9	38	47	16	118	134	3	27	30	-	9	9	220
1970-71	22	38	60	6	101	107	8	37	45	1	2	3	215
1971-72	21	69	90	20	67	87	12	31	33	T	4	4	214
1972-73	1	51	52	4	121	125	7	22	29	T	4	4	210
1973-74	8	32	40	5	163	168	12	39	51	-	12	12	271
1974-75	5	33	38	36	121	157	2	55	57	-	10	10	262
1975-76	41	119	160	29	189	218	11	97	108	1	12	13	499
1976-77	17	57	74	26	202	228	14	105	119	2	27	29	450
1977-78	33	74	107	31	289	320	7	40	47	-	19	19	493
1978-79	7	45	52	3	192	195	3	39	42	T	6	6	295
1979-80	10	31	41	2	222	224	13	41	44	T	24	24	333

Appendix table 2 (cont'd)

	Oct-Dec			Jan-Mar			Apr-Jun			Jul-Sep			Oct-Sep
Year	17-S[a]	18[b]	Total	17-S[c]	18[b]	Total	17-S[a]	18[b]	Total	17-S[a]	18[b]	Total	Total
1980-81	1	35	36	1	189	190	1	89	90	-	14	14	330
1981-82	11	42	53	2	58	60	1	37	38	1	9	10	161
1982-83	3	22	25	1	66	67	12	18	30	T[d]	5	5	127
1983-84	5	21	26	2	33	35	7	5	12	-	20	20	93
Total	402		2126	306		4522	299		1226	22		238	8112
	(18.9)		(100)	(6.8)		(100)	(24.4)		(100)	(9.2)		(100)	
%			26.2			55.7			15.1			2.9	99.9

[a]Foucher and Giudici 1985, Table 4.

[b]Ibid. Table 5.

[c]Appendix table 1.

[d]T = trace = <0.5 t.

Appendix table 3. Landings (t), standardized effort (h), and LPUE-at-age (nos./h) for Pacific cod landed from MSA 14, for selected years, during April-June, July-September, and October-December, 1954-80.

Year	Land. (t)	Effort (h)	LPUE (nos./h) at age: 1	2	3	4	5	6	7	8	9	10
						April-June						
1955	16	53	-	30.1	42.6	29.4	3.8	1.2	-	-	-	-
1956	9	12	-	80.5	127.5	49.4	7.5	2.4	-	-	-	-
1959	2	1	-	940.0	45.0	-	-	-	-	-	-	-
1960	6	22	-	75.6	29.9	7.2	-	-	-	-	-	-
1961	32	82	-	42.8	25.9	3.4	0.9	-	-	-	-	-
1963	5	7	-	350.7	95.0	38.7	-	-	-	-	-	-
1973	58	112	-	57.3	56.7	36.7	26.0	3.5	2.2	-	-	-
1977	34	70	-	98.0	61.6	19.3	8.8	-	-	-	-	-
1978	35	131	-	41.8	34.5	19.7	4.0	-	-	-	-	-
1980	24	94	-	28.6	1.5	1.1	0.7	-	-	-	-	-
						July-September						
1954	32	54	-	46.2	112.6	46.7	8.2	5.7	0.4	1.3	-	-
1956	19	40	-	68.1	55.7	21.4	2.5	2.3	0.5	0.6	-	-
1957	2	4	-	71.0	11.3	21.5	1.0	1.8	-	-	-	-
1959	32	59	-	380.7	6.3	-	-	-	-	-	-	-
						October-December						
1959	26	90	-	74.4	1.5	-	-	-	-	-	-	-
1961	16	77	0.6	4.1	5.1	16.8	2.1	1.2	-	-	-	-
1962	17	73	34.2	20.1	29.5	9.5	0.3	1.7	-	-	-	-
1963	48	387	7.8	28.6	2.3	1.3	0.4	-	-	-	-	-
1969	19	107	42.3	11.8	9.4	5.2	0.5	0.3	0.1	-	-	-
1970	51	255	6.1	59.6	13.7	8.3	0.3	0.4	-	-	-	-
1971	30	240	-	22.5	7.9	2.2	-	-	-	-	-	-
1972	58	266	2.2	49.8	6.0	4.2	1.5	0.3	-	-	-	-
1974	28	98	1.9	43.9	21.5	14.6	2.3	2.3	0.8	-	-	-
1975	26	91	-	26.5	6.4	10.3	0.3	1.3	-	-	-	-
1977	24	118	-	11.3	7.3	2.2	0.4	0.2	-	-	-	0.2

Appendix table 4. Landings (t), standardized effort (h), and LPUE-at-age (nos./h) for Pacific cod landed from North Gulf Islands (MSA 17-S) for selected years, during January-March, April-June, July-September, and October-December, 1954-77.

Year	Land. (t)	Effort (h)	LPUE (nos./h) at age: 1	2	3	4	5	6	7	8	9	10
						January-March						
1958	3	17	-	72.8	15.6	3.0	1.8	0.6	0.5	-	-	-
1959	33	166	0.3	16.3	7.5	11.7	0.3	1.0	-	-	-	-
1967	10	92	-	86.8	11.6	1.1	-	-	-	-	-	-
1968	10	144	-	7.3	0.9	0.5	T	T	-	-	-	-
1969	14	119	0.3	10.5	0.7	0.9	0.1	0.1	T	-	-	-
1970	10	50	5.2	290.0	3.5	21.8	6.1	-	-	-	-	-
1971	6	51	-	48.5	8.9	1.4	1.1	0.3	0.4	-	-	-
1975	28	91	-	258.4	5.4	6.9	0.2	1.2	-	-	0.9	0.6
1976	22	167	-	17.3	14.1	4.3	1.4	-	-	-	-	-
1977	13	48	-	15.6	41.0	31.8	8.8	0.6	1.2	2.3	0.8	0.7
						April-June						
1962	1	UNK[a]	-	-	-	-	-	-	-	-	-	-
1963	50	192	-	57.0	51.4	10.0	0.7	3.8	-	-	-	-
1966	3	UNK	-	-	-	-	-	-	-	-	-	-
1967	2	12	-	87.3	19.8	3.3	-	-	-	-	-	-
1969	8	107	3.0	27.0	0.6	2.7	0.2	0.2	0.2	-	-	-
						July-September						
1958	1	12	-	32.7	3.3	4.0	0.3	0.3	-	-	-	-
1963	5	33	5.0	38.7	7.7	4.8	2.0	-	-	-	-	-
						October-December						
1954	21	93	2.7	34.0	9.2	6.2	0.6	0.6	0.3	-	-	-
1962	2	7	50.7	62.9	12.6	1.1	-	1.3	-	-	-	-
1963	22	189	2.9	10.3	0.7	1.0	0.1	0.2	-	-	-	-
1964	11	127	1.5	4.9	1.8	1.0	0.3	T	0.1	-	-	-
1966	6	66	33.0	1.7	2.3	0.6	0.2	0.2	-	-	-	-
1967	20	236	16.7	8.0	2.9	1.3	-	-	-	-	-	0.1
1968	19	150	35.7	10.4	6.7	1.4	0.9	-	-	-	-	-
1969	9	135	16.1	21.0	5.7	1.2	1.2	0.2	-	-	-	-
1970	22	173	-	75.3	14.2	9.4	0.7	0.8	-	0.1	-	-
1971	21	111	-	27.5	5.4	9.2	1.9	1.2	0.3	-	-	-

[a]UNK = unknown - no interviewed landings.

Appendix table 5. Landings (t), standardized effort (h), and LPUE-at-age (nos./h) for Pacific cod landed from South Gulf Islands (MSA 18) for selected years during April-June and October-December, 1954-83. (The single sample of 137 fish in July 1952 was not processed.)

Year	Land. (t)	Effort (h)	LPUE (nos./h) at age: 1	2	3	4	5	6	7	8	9	10
						April-June						
1960	11	159	-	12.5	11.5	5.3	1.0	-	-	-	-	-
1963	84	228	-	115.4	36.2	25.5	7.3	2.1	-	-	-	-
1970	27	231	-	45.7	9.0	4.6	0.9	-	-	-	-	-
1971	37	319	-	50.5	10.3	6.9	1.5	0.2	0.2	-	-	-
1974	39	236	-	36.5	20.6	0.4	2.9	0.6	1.1	-	-	-
1975	55	188	-	171.0	4.6	2.1	-	-	0.5	-	-	-
1978	40	97	-	14.8	145.7	15.9	6.8	3.4	-	-	-	0.9
						October-December						
1954	177	770	0.9	11.5	6.3	2.5	0.8	0.3	-	-	-	-
1955	139	927	0.1	2.8	2.6	0.3	0.3	-	0.1	-	-	-
1958	31	290	5.2	28.9	4.3	1.6	1.0	-	0.1	-	-	-
1960	60	283	5.8	46.2	11.1	12.6	0.4	-	-	0.1	-	-
1965	25	1042	0.1	0.5	0.2	0.2	-	-	-	-	-	-
1966	52	272	59.6	4.1	3.5	0.6	-	-	-	-	-	-
1967	47	610	13.5	4.4	1.0	0.1	0.2	-	-	-	-	-
1970	38	373	11.7	4.3	2.8	1.6	0.8	-	-	-	-	-
1971	69	338	45.8	32.1	8.3	4.7	0.8	0.5	-	-	-	-
1975	119	783	7.0	43.9	2.6	3.5	0.6	0.8	-	-	-	-
						July-September						
1960	2	2	-	18.5	62.5	83.5	26.5	-	-	-	-	-
1961	11	88	-	50.8	12.7	3.1	0.6	-	-	-	-	-
1974	52	159	-	5.9	43.7	39.5	10.1	3.9	0.7	0.5	-	-
1976	206	582	-	21.2	50.4	9.0	1.6	5.0	0.1	-	0.4	-
1977	100	245	-	61.3	22.2	33.9	10.7	1.3	1.0	-	-	-
1978	173	507	2.5	44.7	53.6	11.0	10.0	2.8	1.1	0.8	-	-
1979	74	251	-	47.6	14.7	5.7	-	-	-	0.5	-	-
1980	374	815	0.4	169.5	21.8	24.4	3.7	3.1	0.6	0.8	0.1	-
1981	209	554	-	171.9	59.6	8.2	5.3	2.4	2.2	-	-	-
1983	160	530	5.4	81.3	6.1	17.7	7.0	0.2	2.5	0.1	-	-

Appendix table 6. Landings (t), standardized effort (h), and LPUE-at-age (nos./h) for Pacific cod landed from MSA 19, for selected years during January-March, April-June, and July-September, 1960-83.

Year	Land. (t)	Effort (h)	LPUE (nos./h) at age: 1	2	3	4	5	6	7	8	9	10
						January-March						
1978	98	333	-	18.2	63.5	18.1	4.2	3.0	-	-	-	-
1979	108	394	-	42.9	11.9	2.4	0.2	1.4	1.0	-	-	-
1980	68	349	-	45.0	5.5	7.4	0.5	1.0	-	0.5	-	-
1981	200	381	-	250.0	42.6	3.6	1.5	4.5	-	-	-	-
1982	304	1078	-	14.3	76.8	5.8	0.5	0.5	-	-	-	-
1983	169	601	-	53.3	5.0	2.8	0.6	-	-	-	-	-
						April-June						
1979	36	106	-	36.4	48.3	16.2	3.5	0.6	-	0.5	-	-
1980	37	169	-	102.9	16.1	7.6	0.4	0.9	0.6	-	-	-

Appendix table 7. Landings (t), standardized effort (h), and LPUE-at-age (nos./h) for Pacific cod landed from MSA 20, for selected years during January-March, April-June, July-September, and October-December, 1954-82.

Year	Land. (t)	Effort (h)	LPUE (nos./h) at age: 1	2	3	4	5	6	7	8	9	10
						January-March						
1966	20	123	-	2.9	14.1	8.3	3.3	0.4	0.3	-	-	-
1978	24	102	-	-	1.5	1.4	0.5	0.3	-	-	-	-
1979	159	448	-	-	5.7	7.1	2.5	1.0	0.2	0.2	0.2	-
1980	199	926	-	0.1	20.0	22.1	9.1	6.0	2.3	0.2	-	-
1982	46	88	-	11.7	87.1	60.1	12.1	1.8	4.1	-	-	-
						April-June						
1960	56	629	-	0.4	20.2	8.8	0.7	0.1	-	-	-	-
1961	15	102	-	0.5	2.5	1.2	0.1	0.1	-	-	-	-
1962	29	349	-	3.3	9.1	3.0	0.1	0.4	-	-	-	-
1975	29	77	-	23.6	32.6	15.0	5.4	3.9	0.6	-	-	-
						July-September						
1954	14	109	-	-	42.7	2.3	1.3	0.2	-	-	0.2	-
1956	16	83	-	4.6	28.7	11.0	2.2	-	0.1	-	-	-
1958	8	136	-	1.6	11.2	1.3	0.6	-	-	-	-	-
1959	24	174	-	37.2	83.7	1.5	0.9	-	-	-	-	-
1969	21	204	-	3.2	7.2	2.7	1.3	0.1	0.5	-	0.1	-
						October-December						
1958	22	188	-	3.6	20.6	0.2	1.0	-	-	-	-	-
1961	16	157	0.1	3.6	7.0	0.8	-	-	-	-	-	-
1962	22	158	1.9	28.1	16.3	6.3	1.9	0.3	-	-	-	-
1965	14	106	0.8	11.8	11.5	3.0	0.5	-	-	-	-	-
1966	28	40	-	69.9	113.0	39.1	27.5	2.0	-	-	-	-
1971	23	103	-	22.3	26.1	7.8	0.3	0.6	0.3	-	-	-